Phenomenology of Higgs Bosons beyond the Standard Model

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outline

- Higgs Bosons: why and what to expect ?

- Higgs bosons in models beyond the SM

- Higgs Bosons: why and what to expect ?

– Electroweak Symmetry Breaking, Higgs mechanism

Theory:		Experiment:
non-Abelian gauge symmetry	→ problem ←	massive gauge bosons exist
forbids $M^2 A_\mu A^\mu$-terms		$(W^\pm, Z)$

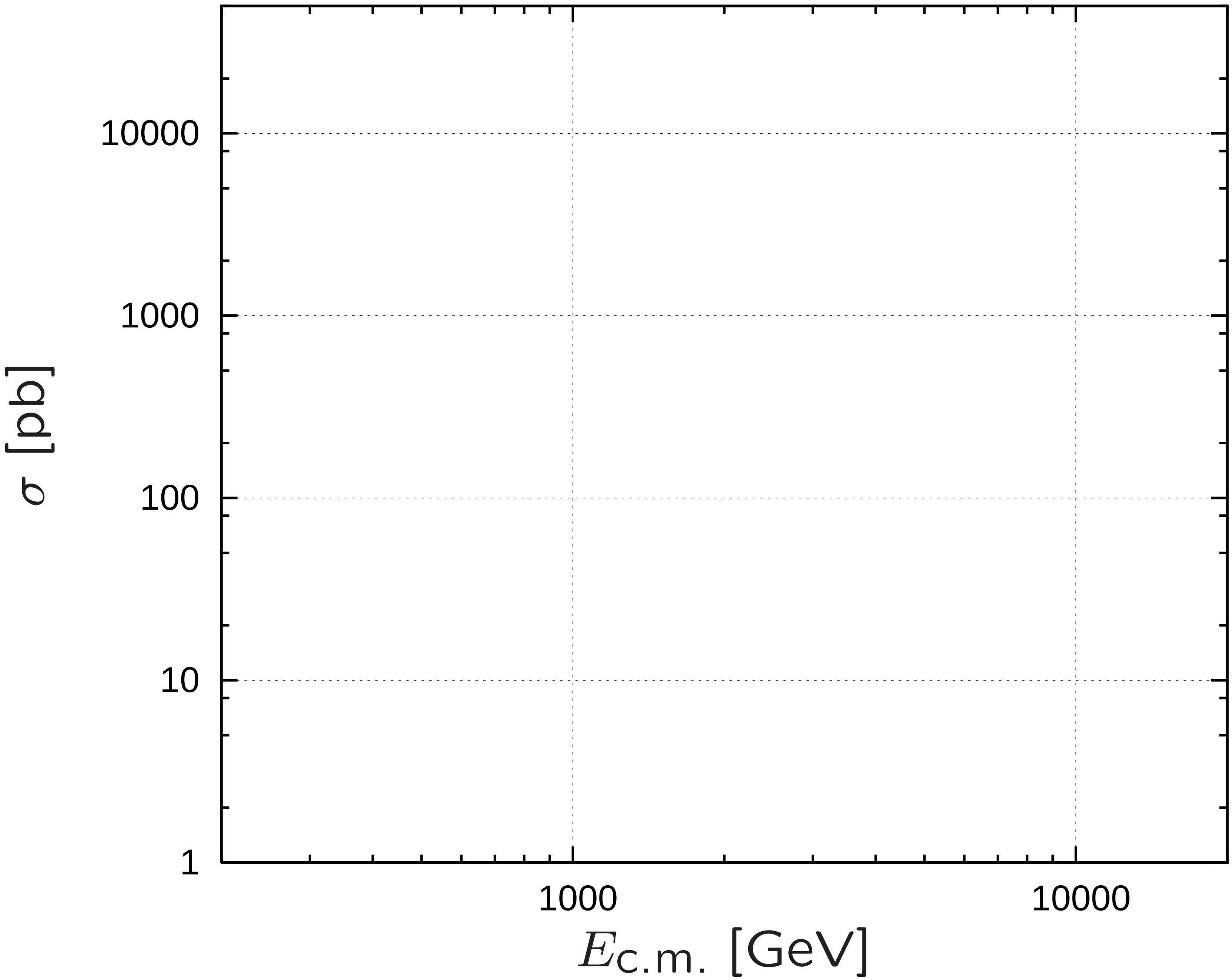
solution: **spontaneous symmetry breaking (SSB)**,

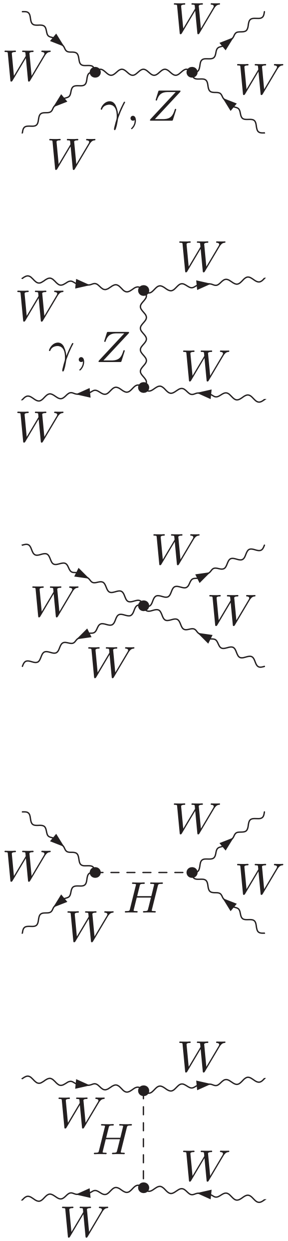
i.e. introduce gauge invariant dynamics, which breaks gauge symmetry in the ground state.

SSB can be realised by

- weakly interacting scalar gauge multiplets that acquire a VEV → Higgs mechanism
- strongly interacting dynamics, e.g. particles that form scalar condensates with a VEV

$\sigma(W_L W_L \to W_L W_L)$ at tree-level





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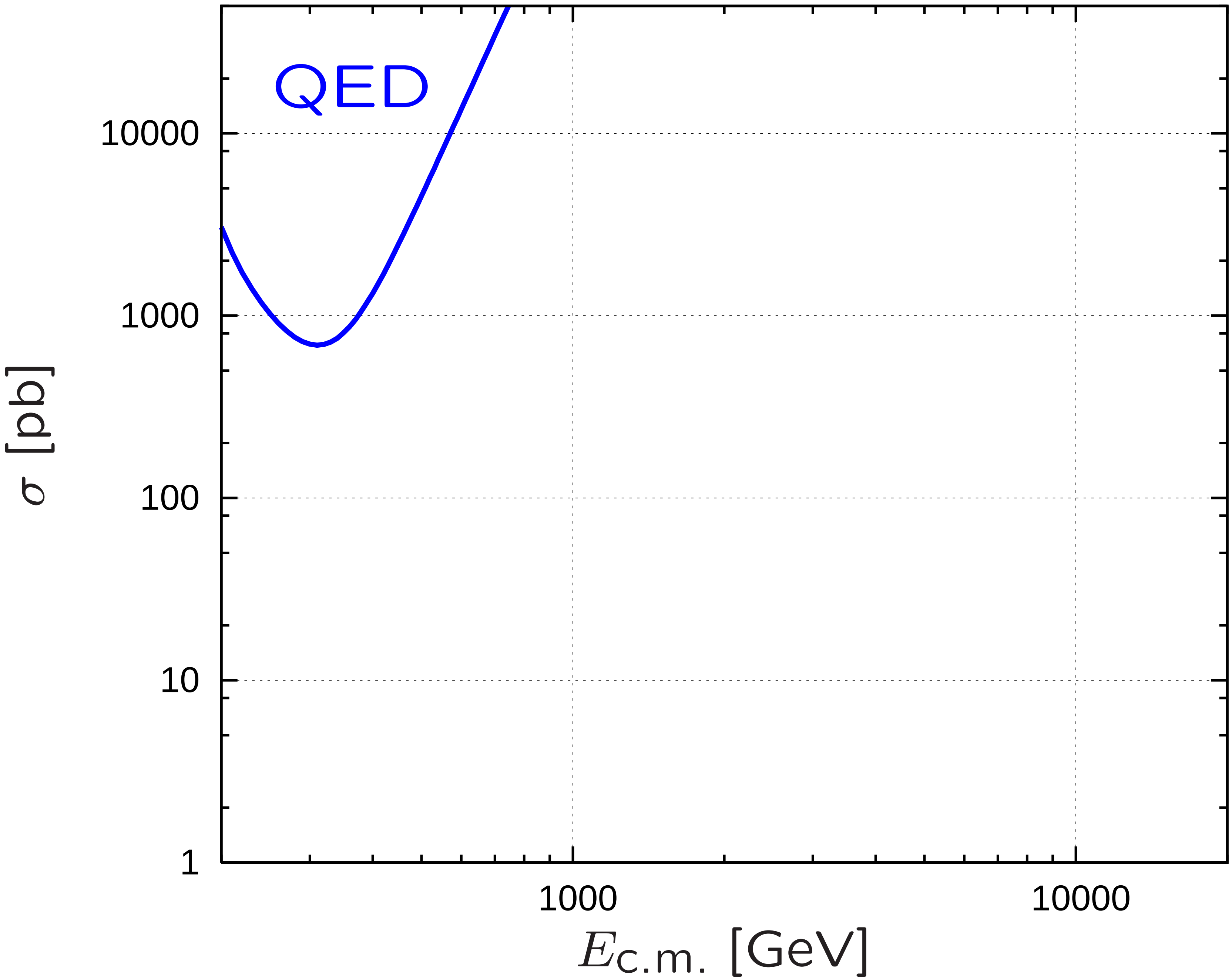

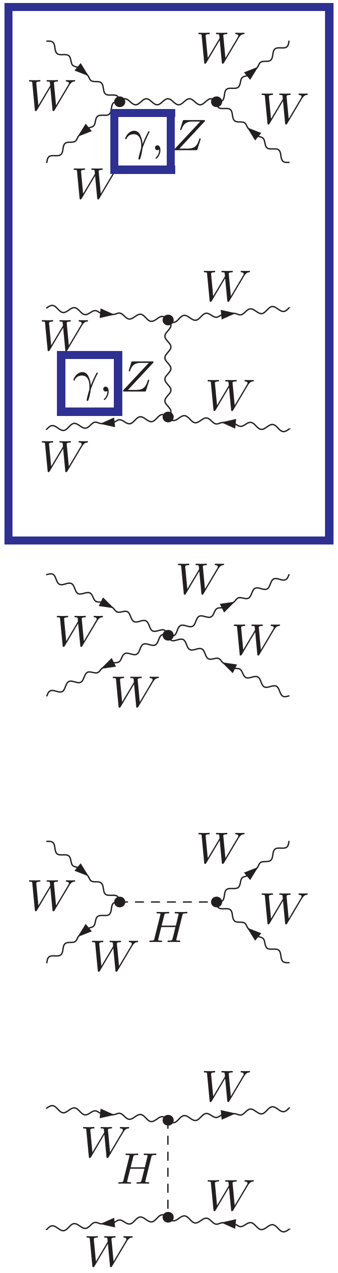

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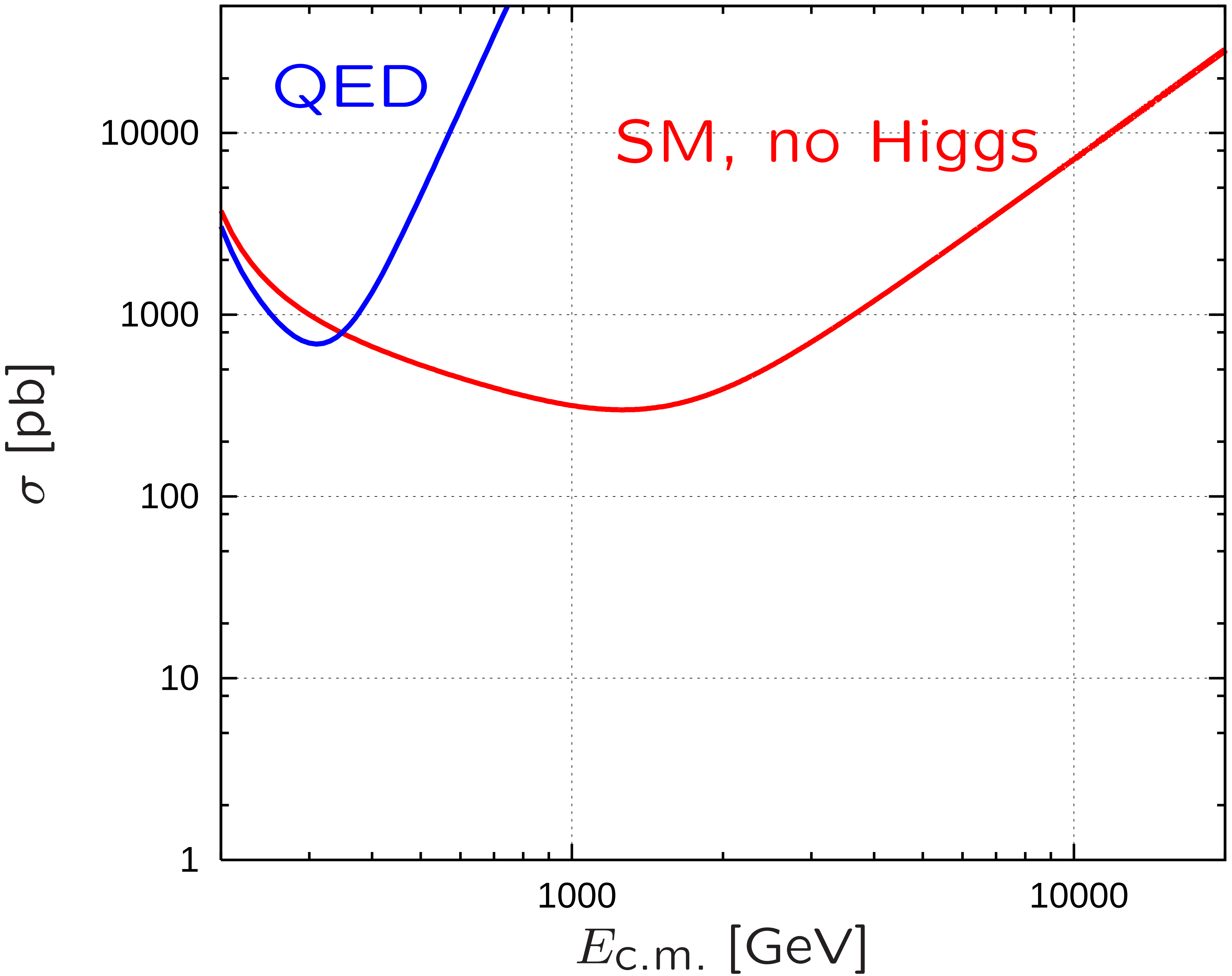

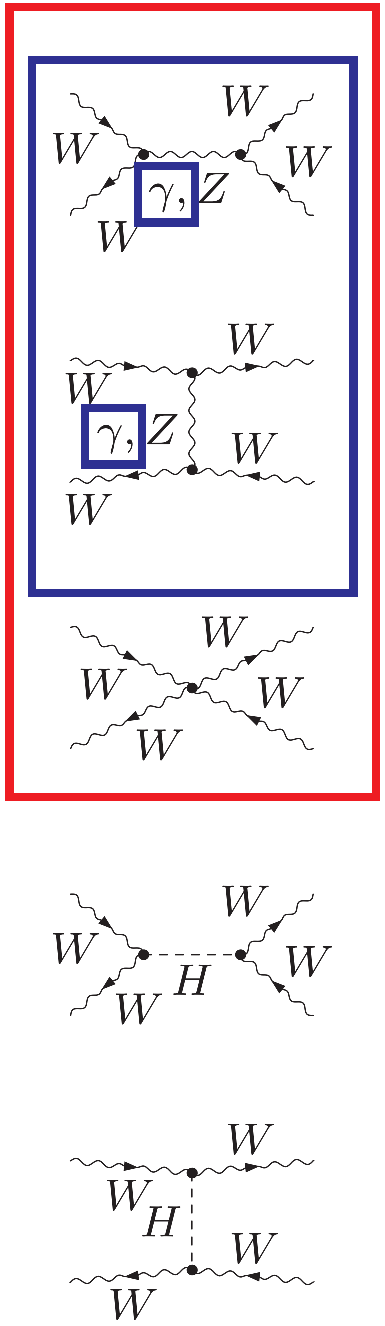

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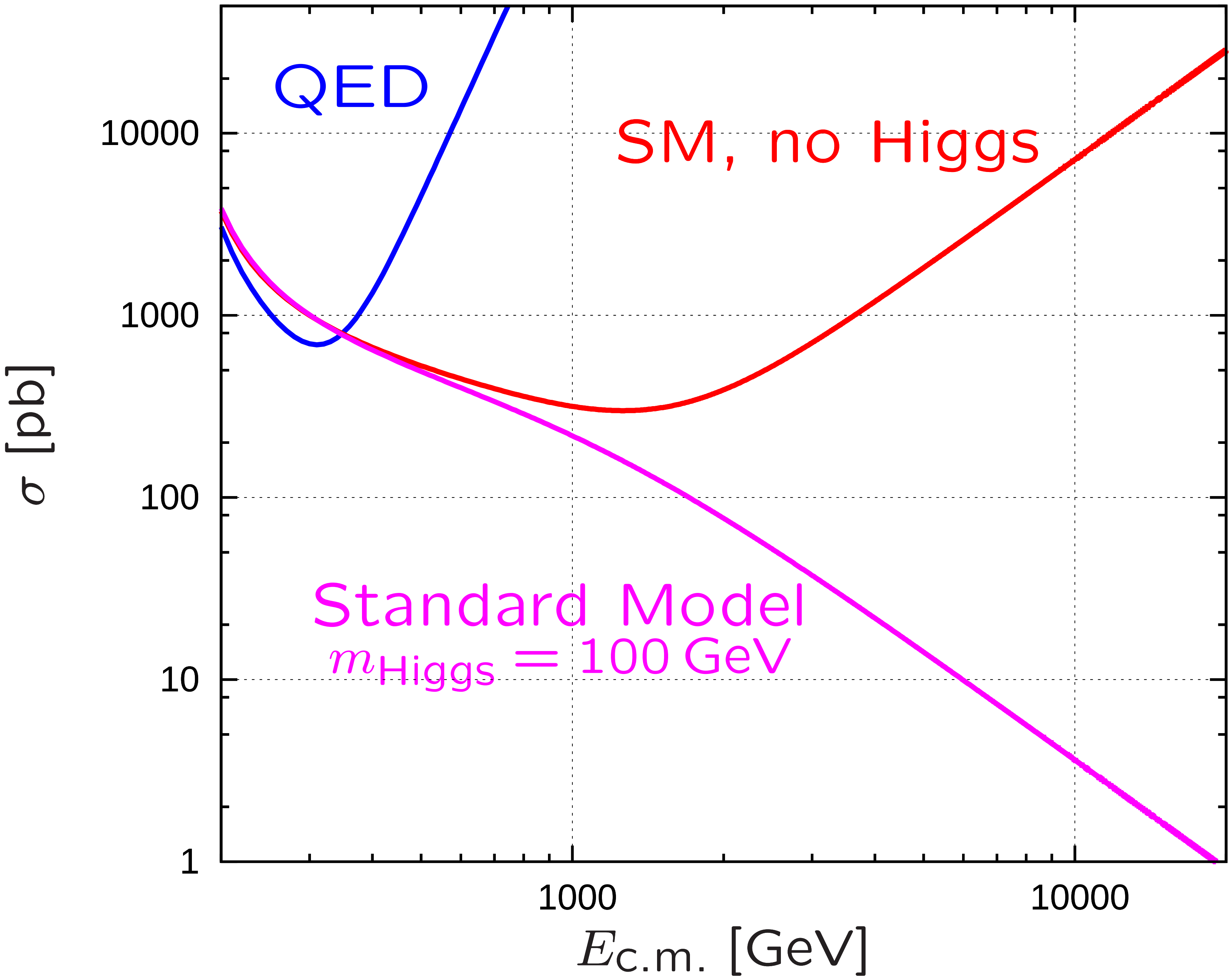
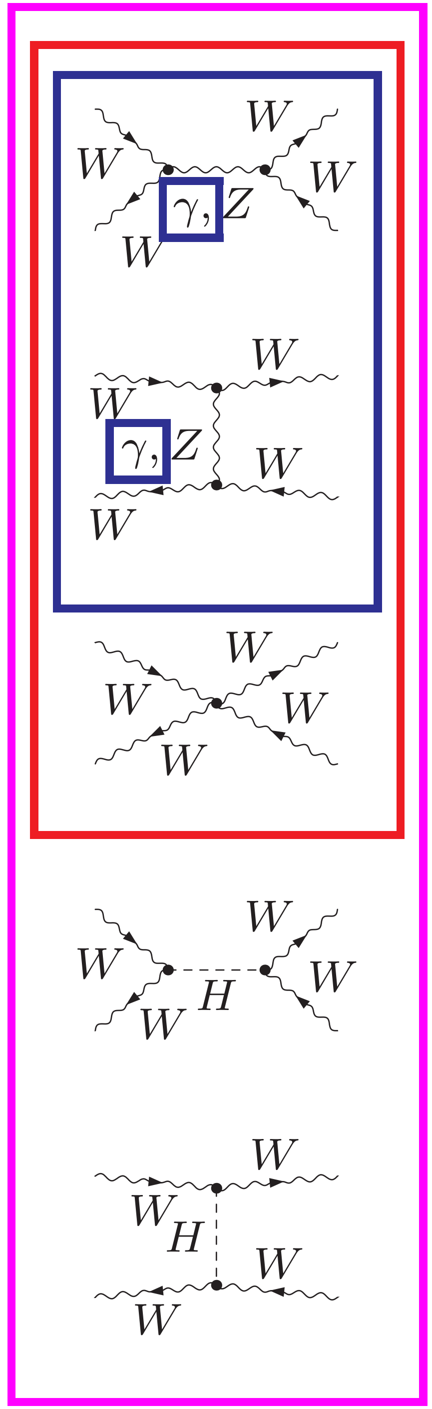




- Restrictions on Higgs sectors

Experimental situation so far:

- no Higgs signal.
- no significant deviation from SM.

Theory:

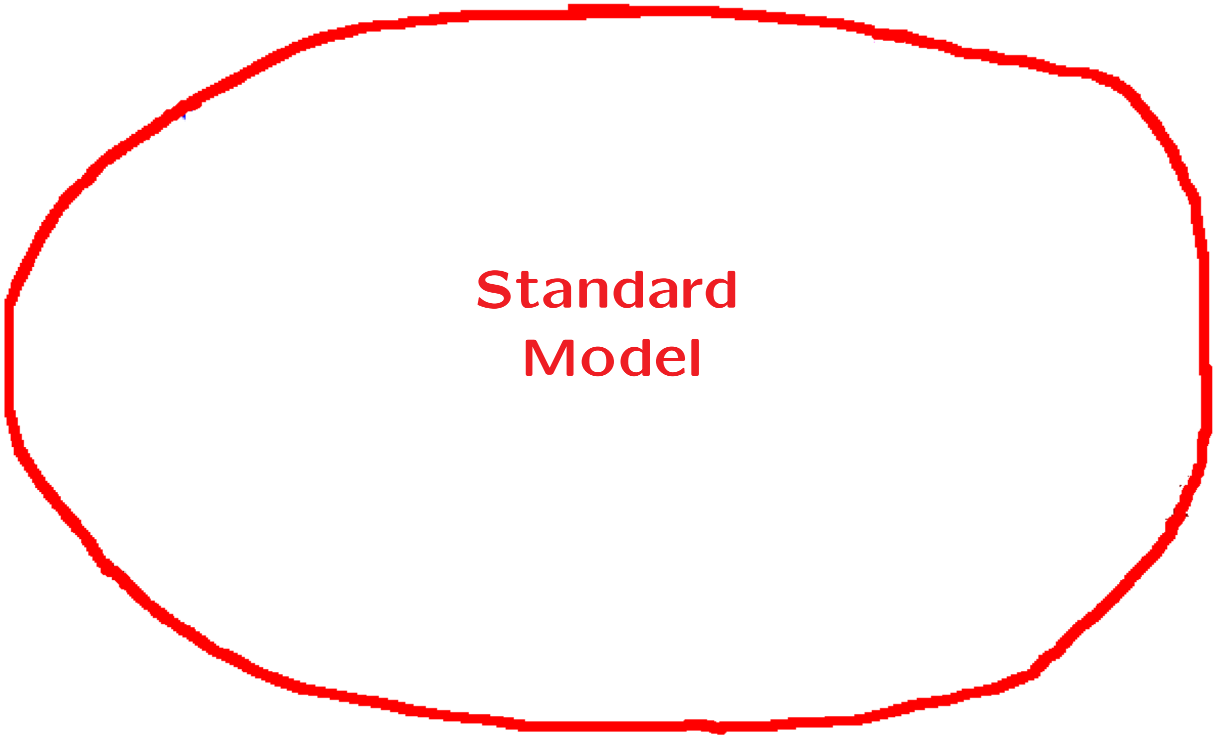
- many distinct possibilities to realise the Higgs mechanism

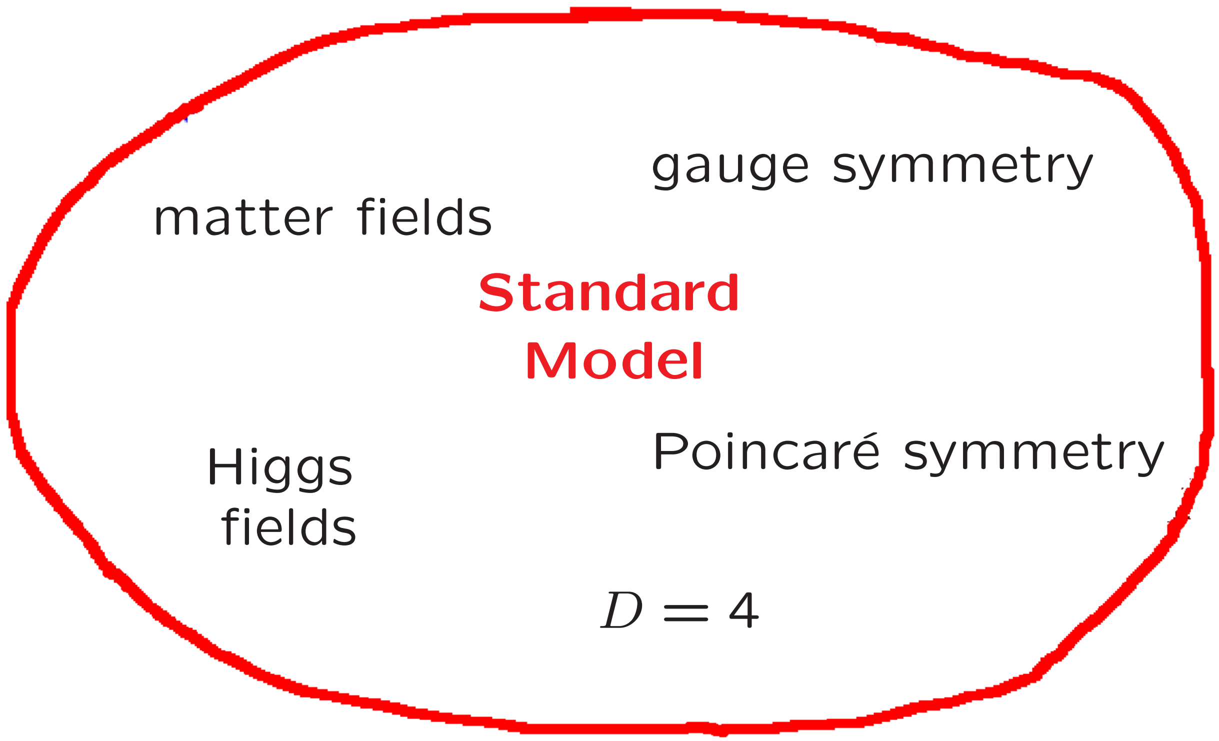
  which meet major constraints, like

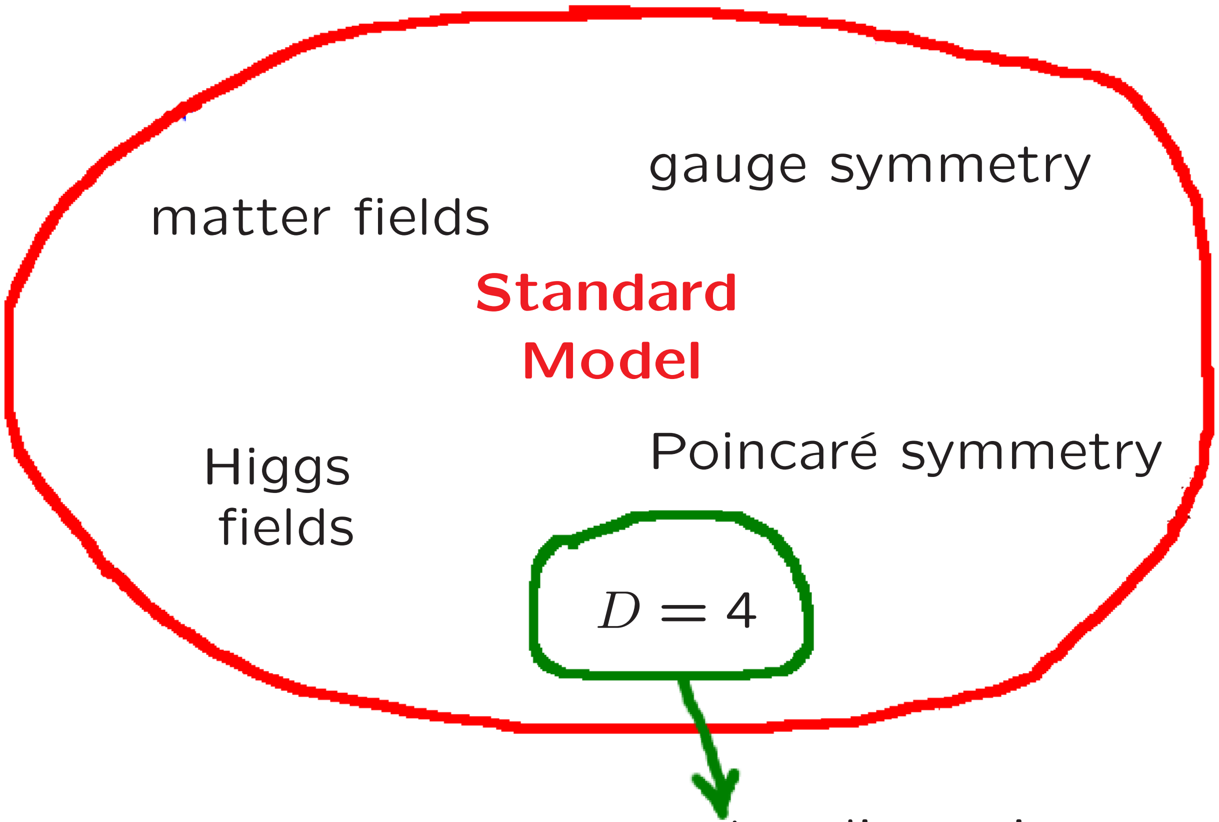
  - the electroweak rho-parameter
    $\rho_{\text{exp.}} = \frac{m_W}{\cos\theta_W m_Z} \approx 1$ up to a few per mille
  - absence of flavour changing neutral currents (FCNC).
  - upper bounds on production cross sections
    from negative direct search results (LEP, Tevatron)

$\longrightarrow$ take extensions of the SM (Higgs sector) seriously

– Beyond the SM: anticipated posibilities




gauge symmetry
matter fields
Standard Model
Poincaré symmetry
Higgs fields
$D = 4$

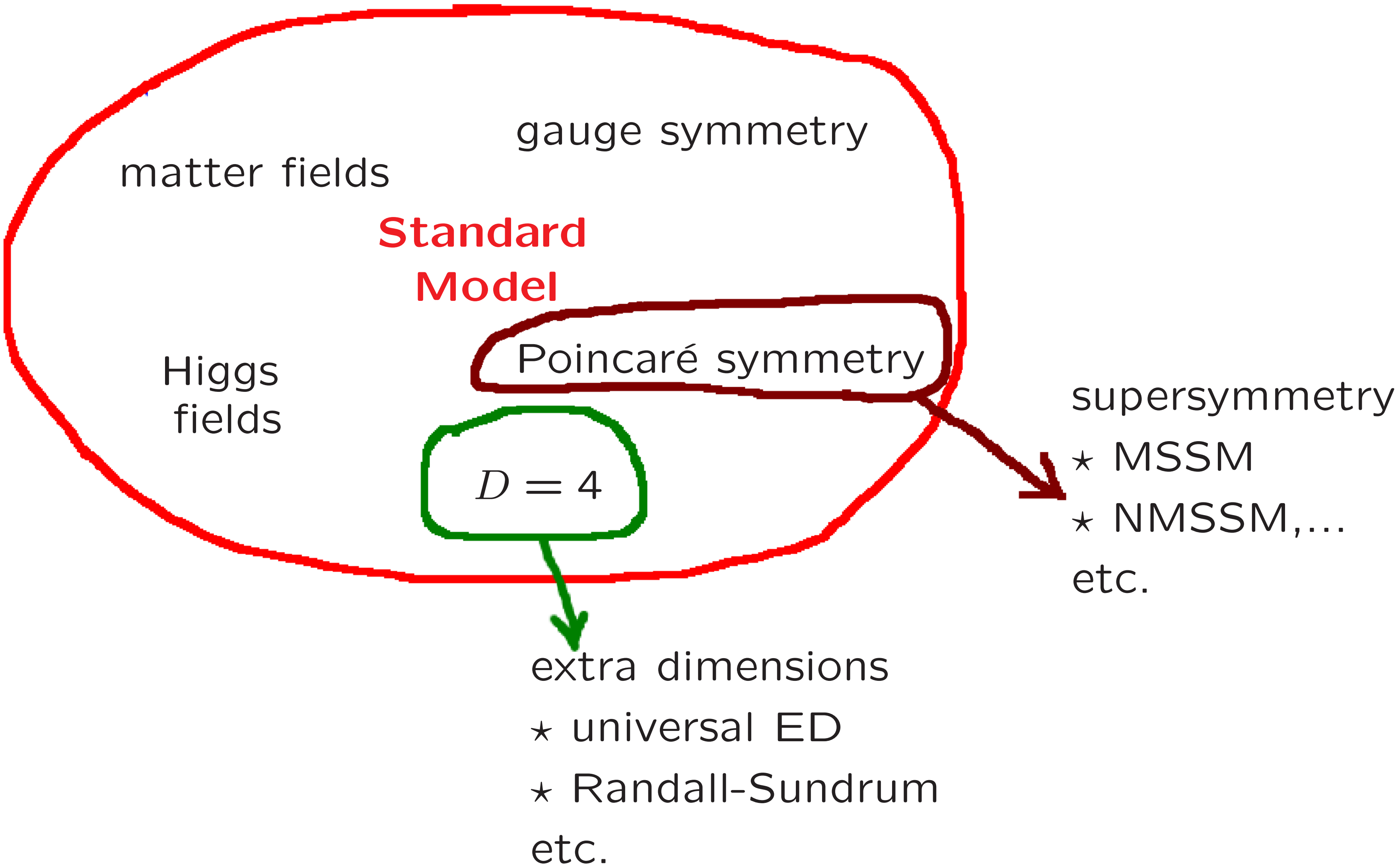


extra dimensions

⋆ universal ED

⋆ Randall-Sundrum

etc.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supersymmetry
⋆ MSSM
⋆ NMSSM,...
etc.
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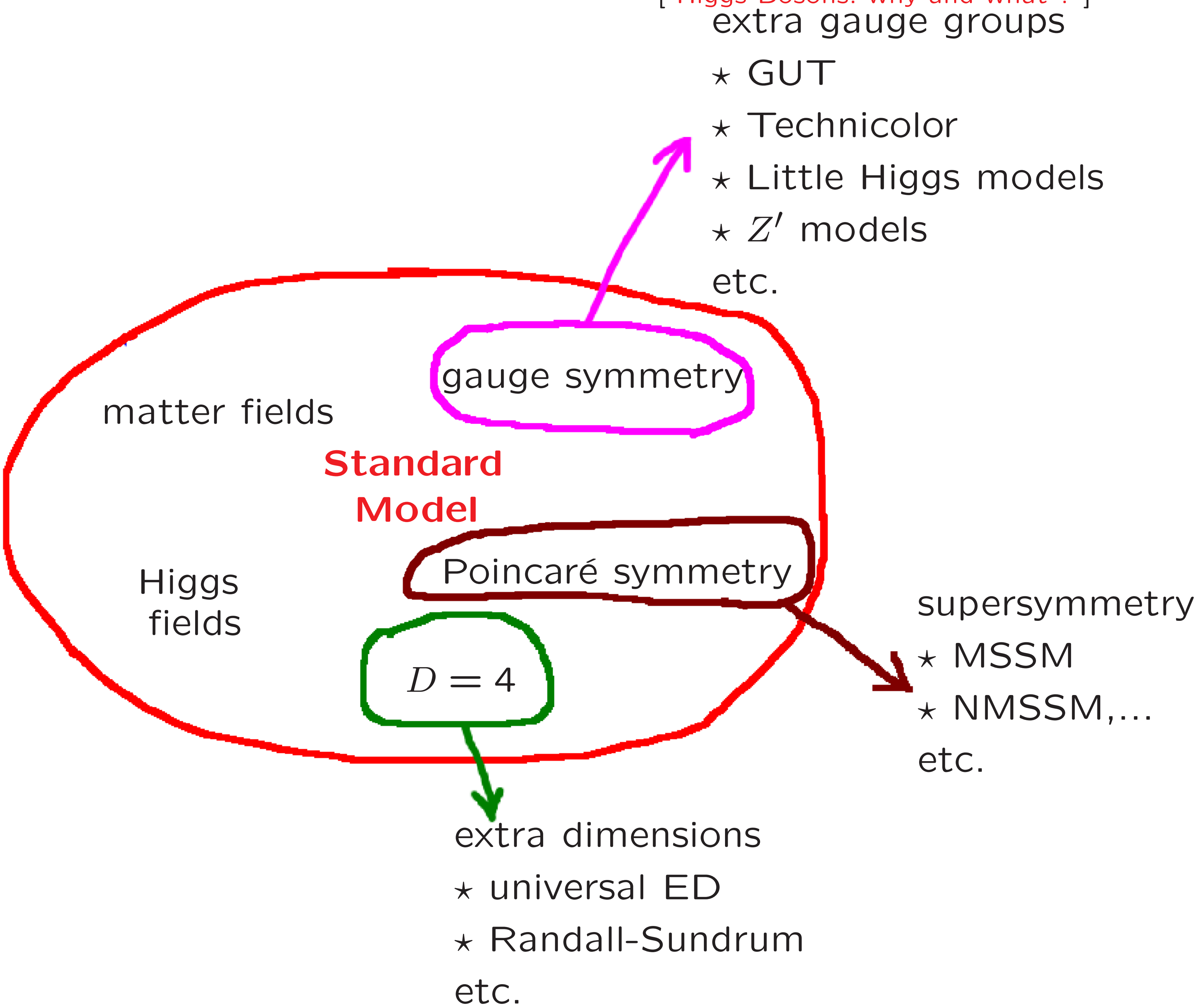
extra gauge groups
⋆ GUT
⋆ Technicolor
⋆ Little Higgs models
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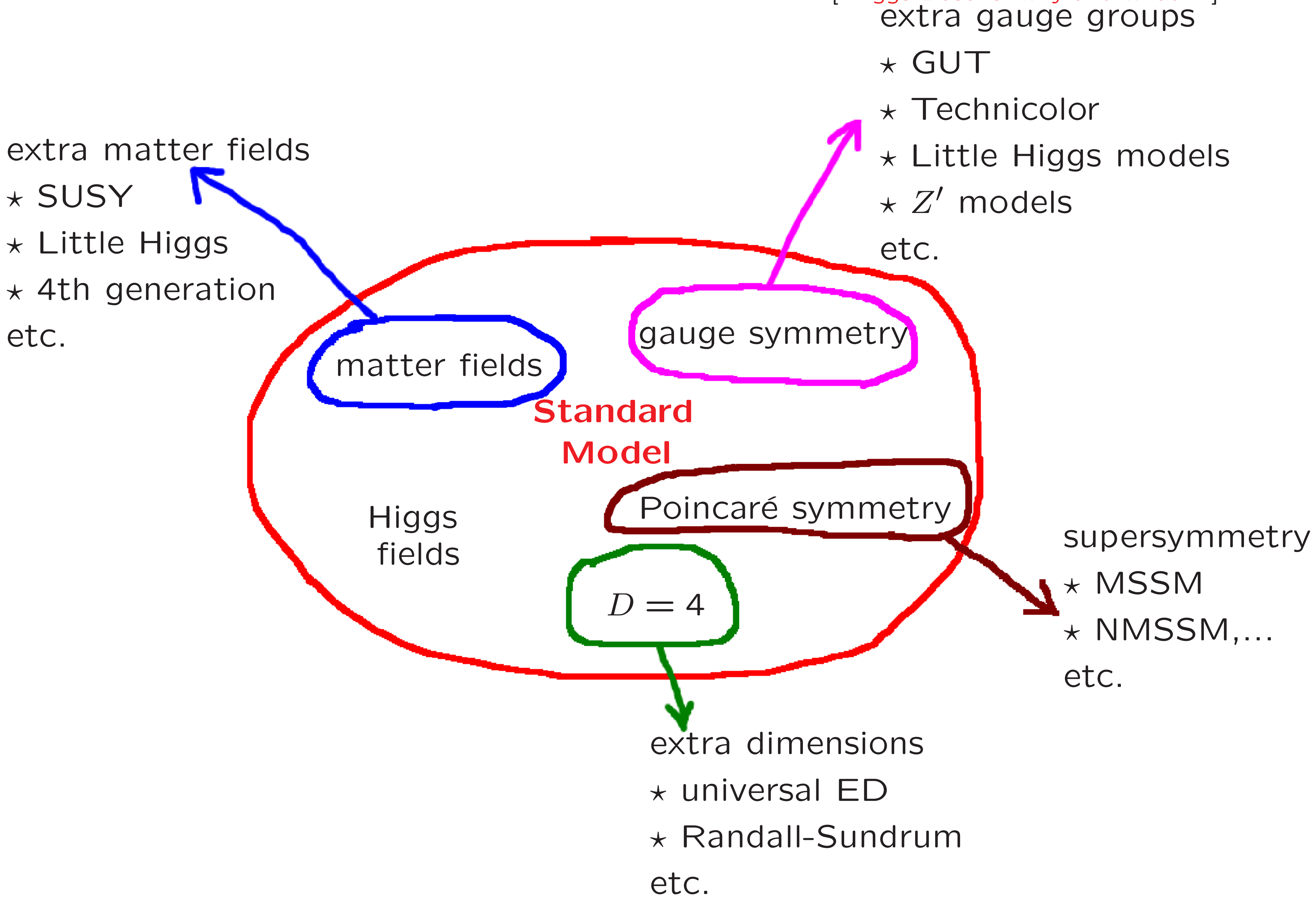
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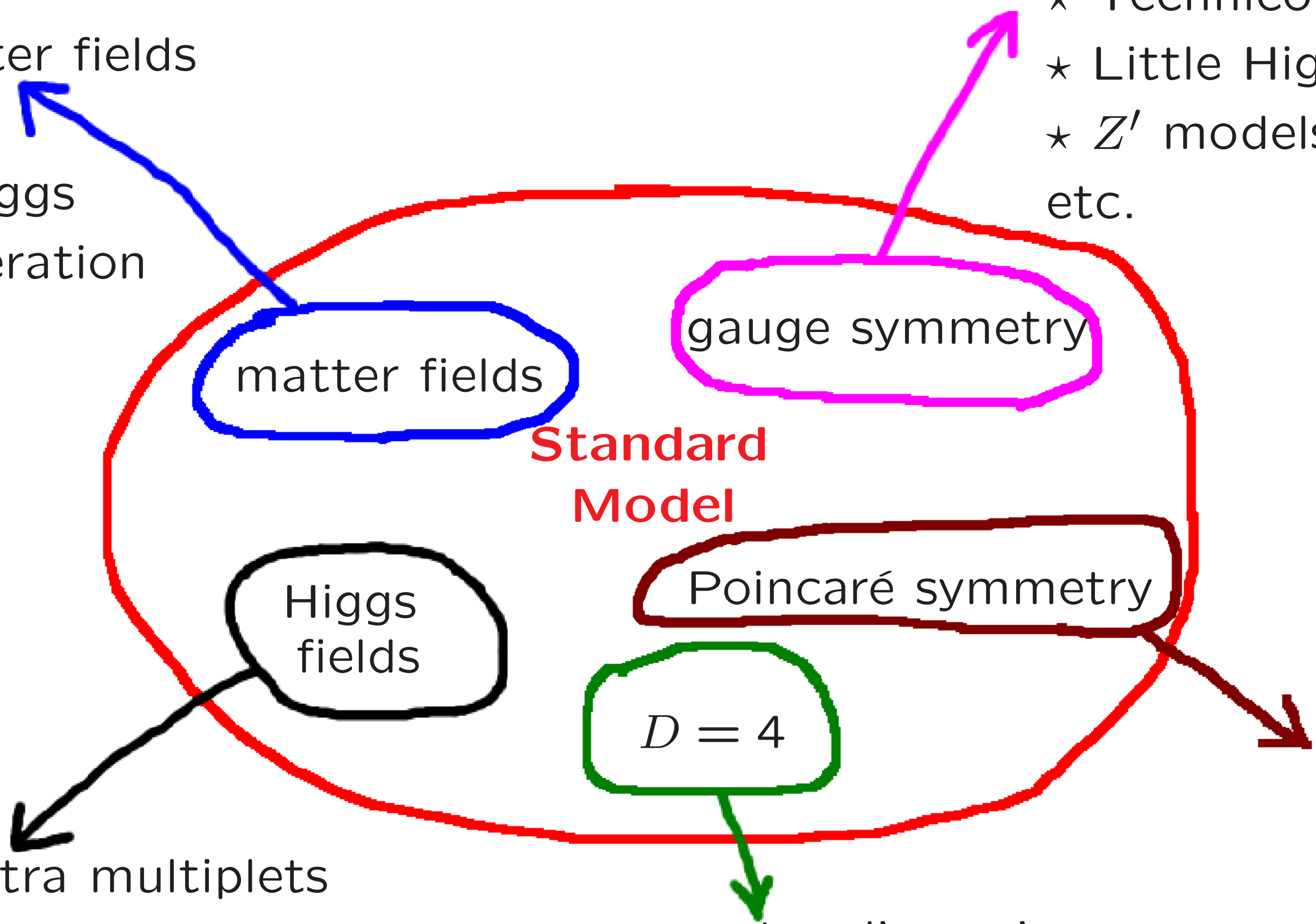


supersymmetry
- ⋆ MSSM
- ⋆ NMSSM,...

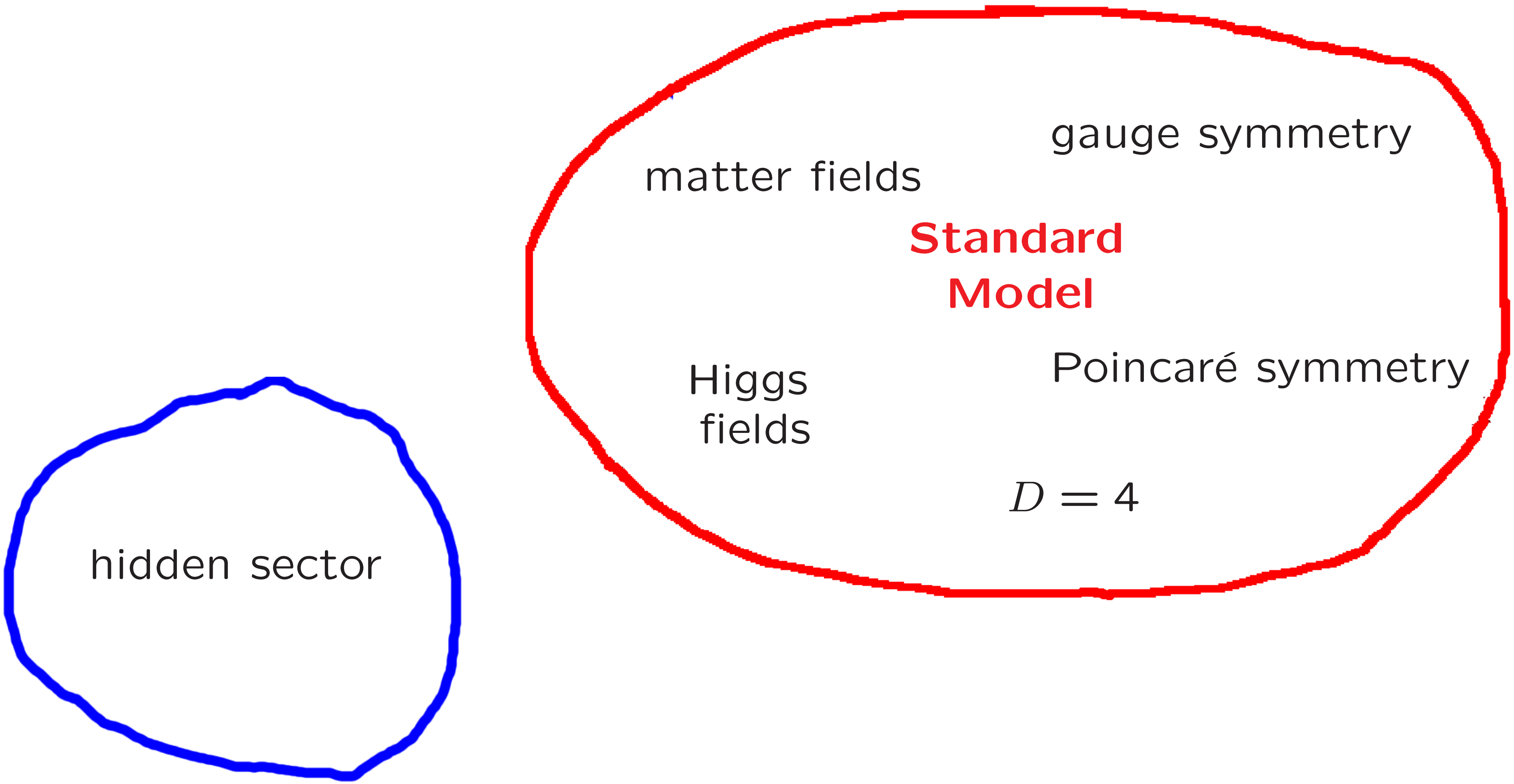
etc.

change/extra multiplets
- ⋆ SUSY
- ⋆ Little Higgs
- ⋆ Higgs triplet models

etc.

extra dimensions
- ⋆ universal ED
- ⋆ Randall-Sundrum

etc.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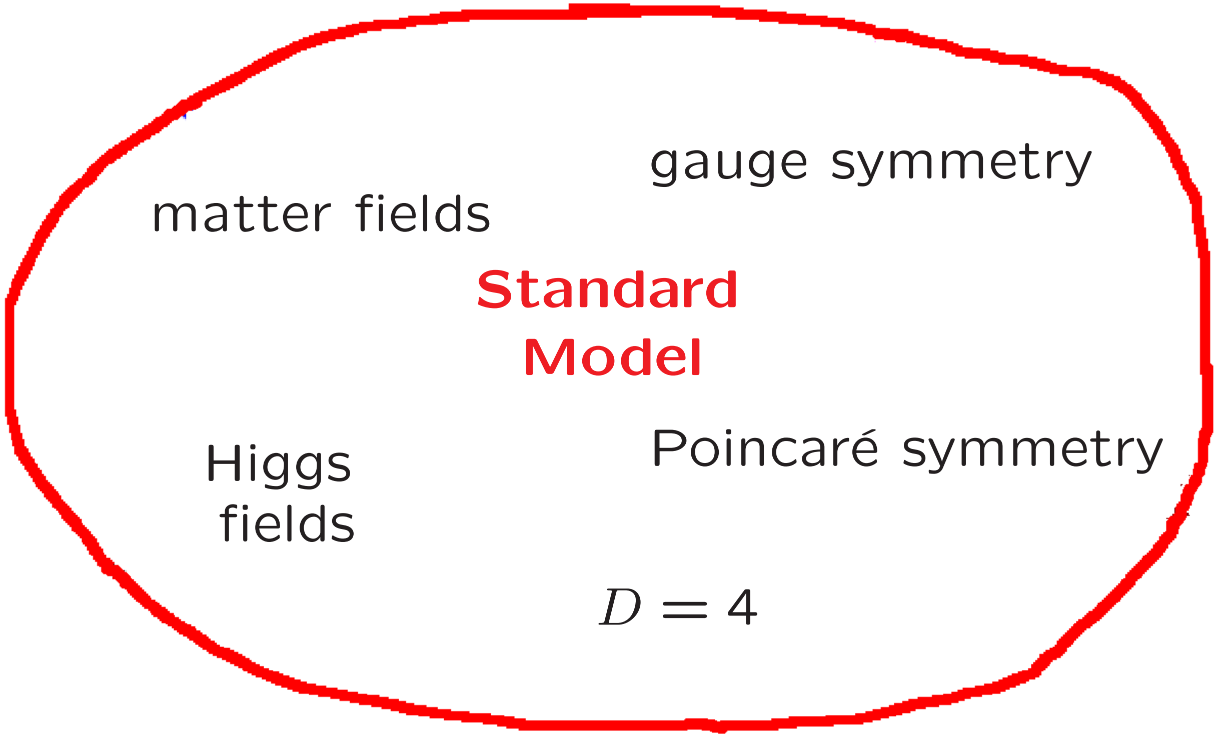
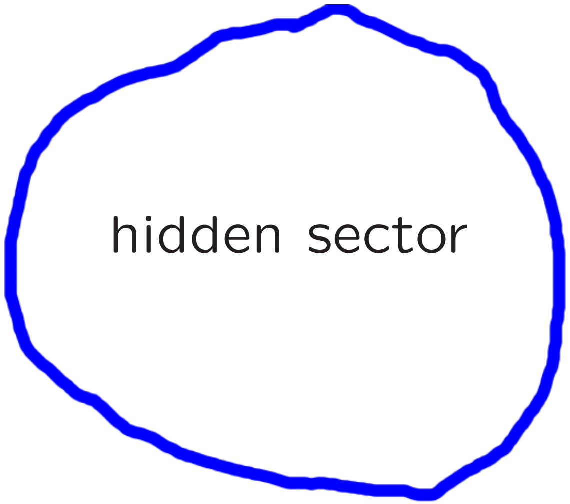
hidden sector





Higgs (Φ): promising “portal” to the hidden sector

via interaction $\mathcal{L} \propto \Phi^{\dagger}\Phi \, \mathbf{O}_{\text{hidden sector}}$

- Higgs bosons in models beyond the SM

• Higgs bosons in models beyond the SM

examples:

- supersymmetric models
- Little Higgs models
- extra dimension models
- scalar sector extensions
- unparticle stuff
- 4th generation model

– supersymmetric models

Supersymmetry . . .

. . . is *the unique* extension of the Poincaré-symmetry of space-time

. . . leads to a symmetry between Fermions & Bosons

gauge theory with minimal SUSY :

- same # of fermionic & bosonic d. o. f.
  $\longrightarrow$ a superpartner of different spin exists for each particle

- couplings are correlated
  $\longrightarrow$ e.g. scalar 4-point int. $\leftrightarrow$ gauge couplings

- superpartners have the same mass
  $\longrightarrow$ SUSY must be broken at the electroweak scale

gauge theory with broken SUSY :

- superpartner masses enter as additional free parameters (essentially)

- real MSSM:

The MSSM with R-parity intact and no new CP-phases ("real MSSM") is (by far) the most well studied model beyond the SM so far.

– content: SM matter, SM gauge bosons
+ 2 Higgs doublets Φ_1, Φ_2 (*only* consistent with 2 doublets)
+ Superpartners

– R-parity: discrete, multiplicative quantum number

$$R\left(\left\{\begin{array}{c}\text{regular particles}\\ \text{superpartners}\end{array}\right\}\right) = \left\{\begin{array}{c}+1\\ -1\end{array}\right. \quad \to \text{FCNC}, \not{L}, \not{B} \text{ avoided}$$

– real-valued SUSY parameters → no new CP-phases introduced

- real MSSM Higgs sector:

– $\Phi_1, \Phi_2 \to$ 5 physical Higgs bosons: h^0, H^0, A^0, H^+, H^-

– all Φ^4-interactions determined by gauge couplings

$\longrightarrow$ only two Higgs sector input parameters: m_{A^0}, $\tan\beta$ $(= v_2/v_1)$

$\longrightarrow$ bound on lightest neutral Higgs mass ($m_{h^0} \lesssim 135\,\text{GeV}$)

– large quantum corrections to Higgs masses (esp. to m_{h^0})

present status:

real MSSM: three-loop (SUSY QCD) precision

[Harlander, Kant, Mihaila, Steinhauser '08]

complex MSSM: two-loop (SUSY QCD) precision

[Heinemeyer, Hollik, Rzehak, Weiglein '07]

more on MSSM Higgs phenomenology $\to$ see talks of: Marina Billoni, Philipp Kant, Michael Rauch, Heidi Rzehak, Martin Spinrath,. . .

• MSSM with R-parity violation:

well motivated: introducing R-parity violating interactions with $\not{L}$

consequences for Higgs phenomenology :

– Higgs bosons mix with sleptons (5 doublets, 3 complex singlets)

6 sneutrino d.o.f. $+$ 3 neutral Higgs d.o.f $\rightarrow$ 5 H_i^0, 4 A_i^0

12 charged slepton d.o.f. $+$ 2 charged Higgs d.o.f $\rightarrow$ 7 $H_i^\pm$

– Higgs-like and slepton-like decay channels open up

– couplings not entirely $\propto$ mass

$\rightarrow$ typical Higgs-signature can be obscured if mixing is strong

- SUSY models with an extra singlet (NMSSM,mnSSM):

Superpotential of MSSM contains μ-term (μ: mass dimension 1):

$$W_{\text{MSSM}} = W_{\text{super-Yukawa}} + \epsilon_{ij}\mu\widehat{H}_d^i\widehat{H}_u^i$$

$$\mathcal{L}_{\text{soft}} = -m_{H_d}^2|H_d|^2 - m_{H_u}^2|H_u|^2 - (\mu B_\mu \epsilon_{ij} H_u^i H_d^j + \text{h.c.})$$
$$+ [\text{sfermion} + \text{gaugino mass terms}]$$

problem:

Higgs mass formulae: μ should be $\approx \mathcal{O}$(SUSY breaking scale) $\leftrightarrow$ supersymmetric GUT: μ should be of order M_{GUT}

solution: MSSM + singlet superfield $\widehat{S}$ (contains complex scalar field S):

- in the minimum of the scalar potential H_u, H_d, S acquire VEVs
- MSSM μ-term generated dynamically $\mu_{\text{eff}} = \lambda\langle S\rangle$ (λ dimensionless)
- μ_{eff} is naturally $\mathcal{O}$(SUSY breaking scale)

- SUSY models with an extra singlet (NMSSM,mnSSM):

variant 1: NMSSM (Next-to-minimal supersymmetric Standard Model)

$$W_{\text{NMSSM}} = W_{\text{super-Yukawa}} + \epsilon_{ij}\lambda\widehat{S}\widehat{H}_d^i\widehat{H}_u^i + \frac{\kappa}{3}\widehat{S}^3$$

$$\begin{aligned}\mathcal{L}_{\text{soft}} = & -m_{H_d}^2|H_d|^2 - m_{H_u}^2|H_u|^2 - m_S^2|S|^2 \\ & - (\lambda A_\lambda \epsilon_{ij} S H_u^i H_d^j + \frac{\kappa}{3}A_\kappa S^3 + \text{h.c.}) \\ & + [\text{sfermion} + \text{gaugino mass terms}]\end{aligned}$$

variant 2: mnSSM (minimal non-minimal supersymmetric Standard Model)

[Panagiotakopoulos, Pilaftsis ’00; Dedes et al. ’00]

$$W_{\text{mnSSM}} = W_{\text{super-Yukawa}} + \epsilon_{ij}\lambda\widehat{S}\widehat{H}_d^i\widehat{H}_u^i \; [+t_F\widehat{S}]$$

$$\begin{aligned}\mathcal{L}_{\text{soft}} = & -m_{H_d}^2|H_d|^2 - m_{H_u}^2|H_u|^2 - m_S^2|S|^2 + t_S S \\ & - (\lambda A_\lambda \epsilon_{ij} S H_u^i H_d^j + \text{h.c.}) \\ & + [\text{sfermion} + \text{gaugino mass terms}]\end{aligned}$$

t_F-term usually too suppressed to play a role at TeV-colliders

variant 3 to n: ...

- NMSSM/mnSSM Higgs phenomenology :

similar features:

– Higgs sector: 2 doublets + 1 complex singlet → $H_1^0, H_2^0, H_3^0, A_1^0, A_2^0, H^\pm$

– relaxed theoretical upper bound on the lightest Higgs mass (≈ 150 GeV)

– relaxed LEP-bound on mass of H_1^0 and $H^\pm$ (about 80 GeV, → plot)

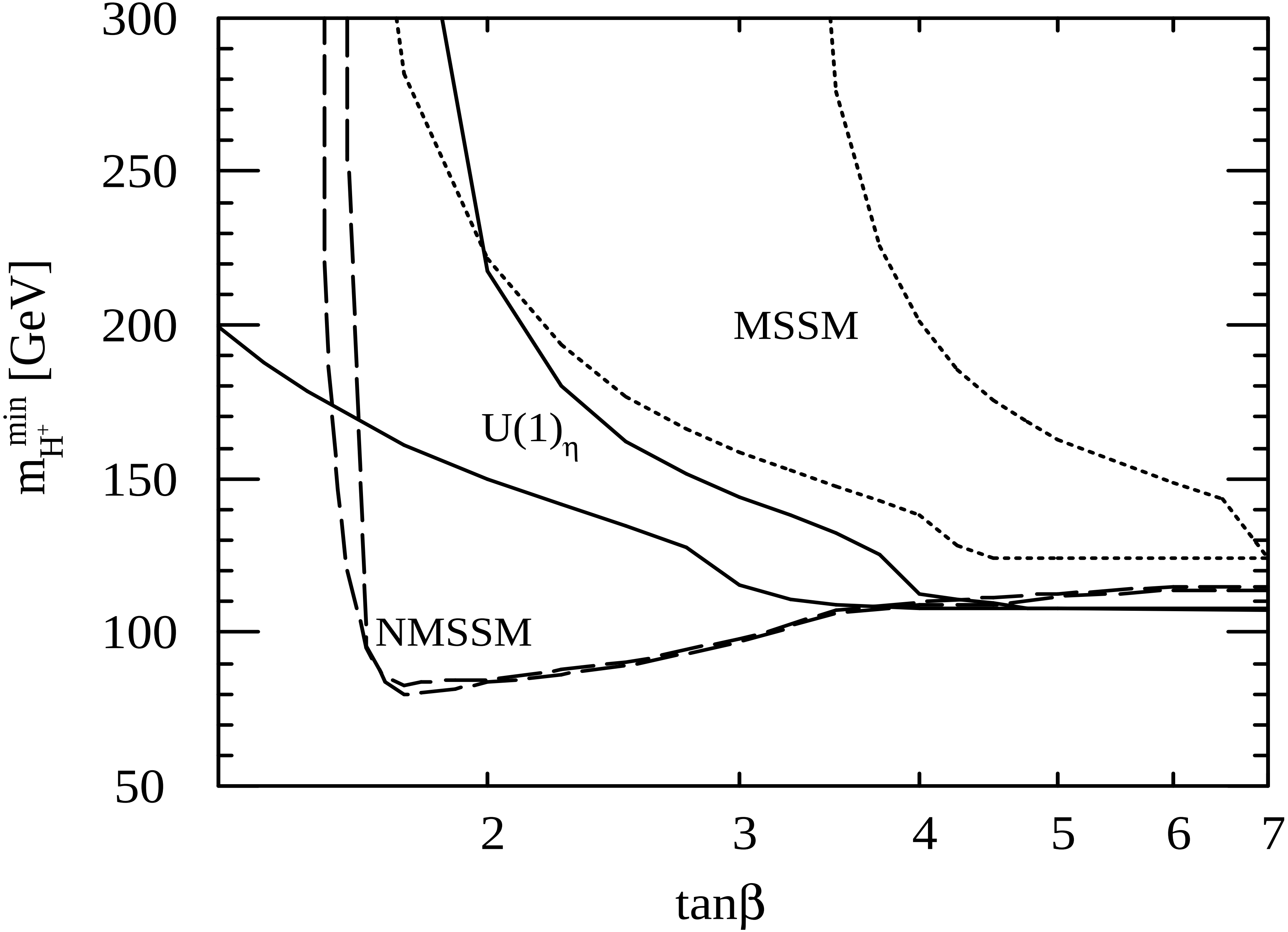
– $H^\pm$ production and decay in LO unchanged compared to MSSM

– Decays heavy Higgs → 2 Higgs bosons often possible
→ problematic to see at LHC if lighter Higgs bosons decay mainly to $b\bar{b}$

example: relaxed indirect $H^{\pm}$ mass bound in NMSSM:

$m_{H^\pm} \approx m_W^2 + m_{A_1}^2 - \lambda^2 v^2/2$ and LEP-bound on m_{A_1} lower than on m_A^{MSSM}

[Drees et al.'98; Godbole, Roy '06]



• NMSSM/mnSSM Higgs phenomenology :

distinctive features:

– # of Higgs sector parameters: 6 (NMSSM) and 5 (mnSSM)

→ mnSSM more restrictive than NMSSM, e.g.:

– mnSSM mass sum rule (not present in NMSSM) :

$$m_{H_1}^2 + m_{H_2}^2 + m_{H_3}^2 = m_Z^2 + m_{A_1}^2 + m_{A_2}^2$$

– mnSSM Higgs-Z coupling complementarity :

$$g_{H_1ZZ}^2 = g_{H_2A_1Z}^2 \,, \qquad\qquad g_{H_2ZZ}^2 = g_{H_1A_1Z}^2$$

→ testing such relations crucial to distinguish between the models

– Little Higgs models

[Arkani-Hamed, Cohen, Georgi '01]

motivation: Higgs boson naturally light if Higgs mass protected
by a symmetry (i.e. mass $\to 0$ should increase symmetry)

well-known: supersymmetry

here: shift symmetry $\to$ Higgs bosons as pseudo-Goldstone bosons

classical naturalness argument:

Higgs mass m_H sensitive to cut-off scale Λ of the theory:
one expects $M_H \propto (\frac{g}{4\pi})\Lambda$ (from one-loop rad. cor.)
$\to$ with $g \approx \mathcal{O}(1)$ and $m_H = \mathcal{O}(100)$ GeV from EW precision data
one gets $\Lambda \approx 1$ TeV
$\to$ strong coupling dynamics should set in at around 1 TeV
$\to$ ruled out by EW precision data!

idea of Little Higgs models: one-loop rad. cor. cancel due to a symmetry

Then $M_H \propto (\frac{g}{4\pi})^2\Lambda \to m_H = \mathcal{O}(100)$ GeV for $\Lambda \approx 10$ TeV
$\to$ Higgs naturally light *and* no problems with EW precision data

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Then $M_H \propto (\frac{g}{4\pi})^2 \Lambda \to m_H = \mathcal{O}(100)$ GeV for $\Lambda \approx 10$ TeV

$\to$ Higgs naturally light *and* no problems with EW precision data

realization: collective symmetry breaking principle

$\to$ class of models (effective theories, applicable up to ≈ 10 TeV)

$\to$ new TeV-scale (f) gauge bosons, fermions and scalars appear

$\to$ at the EW-scale only scalars appear

Higgs sectors of LH models

Model	EW-scale scalars	TeV-scale f scalars
Minimal moose	$\Phi_1, \Phi_2, \Sigma, S^c$	(none)
Minimal moose with SU(2)$_C$	Φ_1, Φ_2	$\Sigma^r, S^c_\pm, S^r$
Moose with T-parity	Φ_1, Φ_2	$\Phi_{3,4,5}, \Sigma^r_{1,2,3}, S^c_{1,..,5}, P_{1,2,3}$
Littlest Higgs	Φ	Σ
SU(6)/Sp(6) model	Φ_1, Φ_2	S^c
Littlest Higgs with SU(2)$_C$	Φ	Σ, Σ^r, P
Littlest Higgs with T-parity	Φ	Σ
SU(3) simple group	Φ, P	(none)
SU(4) simple group	Φ_1, Φ_2, P_1, P_2	S^c_1, S^c_2, S^c_3
SU(9)/SU(8) simple group	Φ_1, Φ_2	S^c_1, S^c_2

with Φ scalar doublet,
S^c complex scalar singlet,
S^r real scalar singlet,
P pseudoscalar singlet,
Σ complex triplet,
Σ^r real triplet.

(some) consequences for Higgs phenomenology:

example: Littlest Higgs model : 1 doublet at EW scale

– Higgs couplings identical to SM up to $\frac{v}{f}$-corrections ($\frac{v}{f} \approx \frac{250}{1000} = \frac{1}{4}$)
  → $\sigma \times$BR deviates from SM by $(\frac{v}{f})^2 \approx$ few %.
  → requires % accuracy measurements to distinguish from SM

– Test of divergency cancellation relations:
  The 4-point interactions of a Higgs boson H
  with heavy gauge bosons V_i have to fulfil

$$\sum_i G_{HHV_iV_i} = 0$$

  in order to cancel one-loop quadratic divergencies in Higgs self energy.
  After EWSB: $G_{HHV_iV_i}$ give rise to $G_{HV_iV_i}$-couplings.

  → Measurement of all $\sigma(q\bar{q} \to V_i^\star \to HV_i)$ gives information on $G_{HHV_iV_i}$.

– extra dimension models

basic concept: spacetime has $D = 4 + \delta$ dimensions,
δ extra spatial dimensions compactified.

variants:

- large extra dimensions [Arkani-Hamed, Dimopoulos, Dvali '98]
  - only gravity propagates in extra dimensions
  - size (R): up to submillimetre length
  - 4d Planck mass $M_{Pl}^2 \propto R^\delta M_D^{2+\delta}$, M_D : fund. D-dim. Planck mass
  - $\delta = 1$ ruled out (planetary motion)
- warped extra dimensions [Randall, Sundrum '99]
  - gravity and SM fields localized at boundaries of a slice of 5d anti-de Sitter space
  - in principle only gravity propagates in extra dimensions
- TeV^{-1}-sized extra dimensions [Antoniadis '90, . . .]
  - in principle all fields propagate in extra dimensions

- large extra dimensions: consequences for Higgs phenomenology

  – Higgs can mix with “graviscalars” via the interaction

$$\mathcal{L} = -\xi \sqrt{-g_{\mathrm{ind}}}\, R(g_{\mathrm{ind}})\, \Phi^\dagger \Phi$$

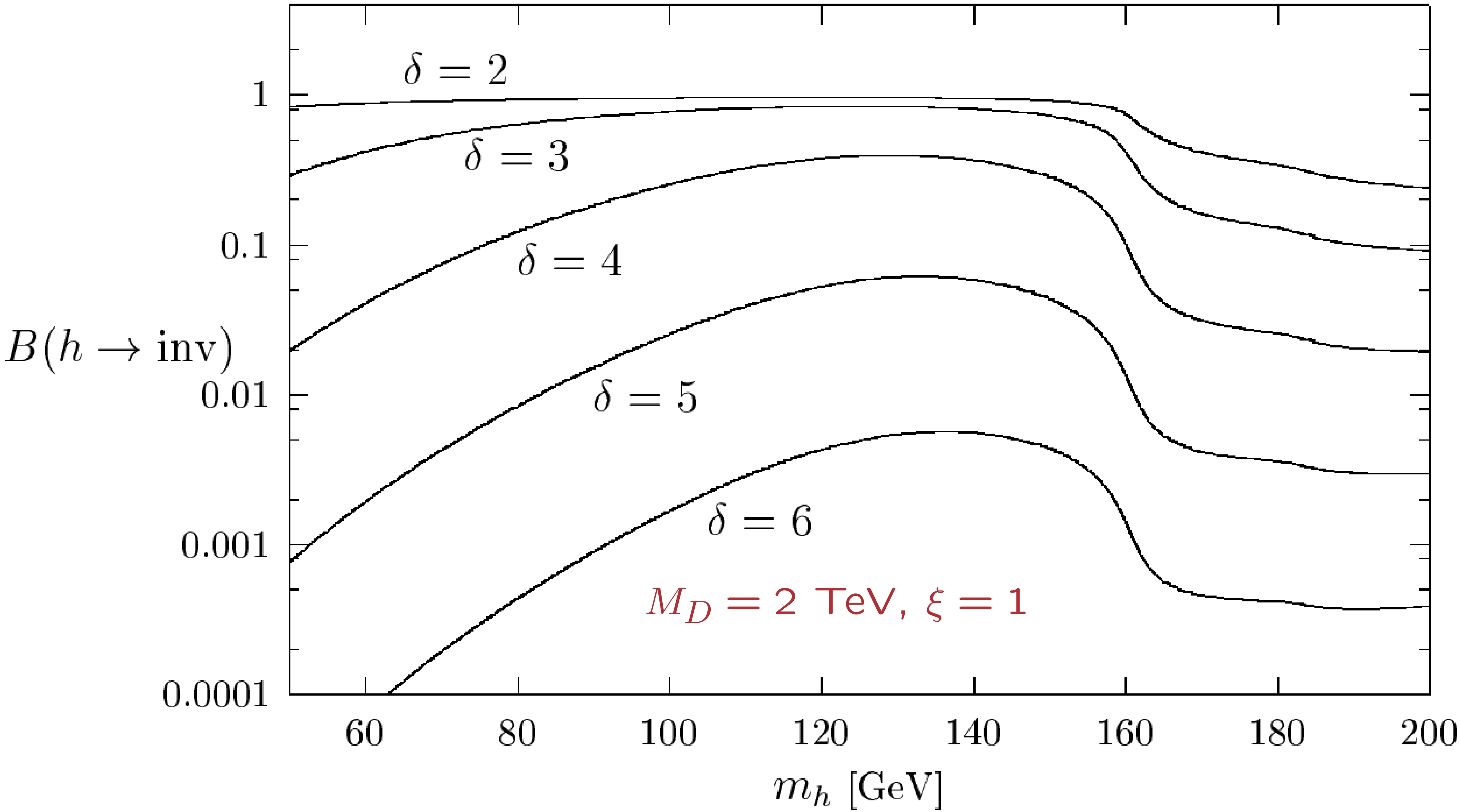
  with g_{ind}: induced 4d metric, R: Ricci scalar.

  – Graviscalars: from extra dimensional entries in D-dim. metric ,
  KK states very dense (quasi continuum)
  $\rightarrow$ sum over contributions compensates for Planck scale suppression

  – large BR($H \rightarrow$ invisible) possible $\rightarrow$ missing energy signature

- large extra dimensions, $D = 4 + \delta$: BR($H \to$ invisible)

[Giudice, Rattazzi, Wells '00]



- warped extra dimensions: consequences for Higgs phenomenology

example: Randall-Sundrum model

– There is one graviscalar in 5d: the radion φ
  (typically the lightest new particle to appear)

– Higgs – radion mixing (again) via the interaction

$$\mathcal{L} = -\xi \sqrt{-g_{\text{ind}}}\, R(g_{\text{ind}})\, \Phi^\dagger \Phi$$

→ Radion φ and physical Higgs h mix to form two mass eigenstates

– φ coupling to massive fermions and gauge bosons $\propto$ mass,
  $\varphi\, b\bar{b}$ coupling suppressed wrt SM Higgs

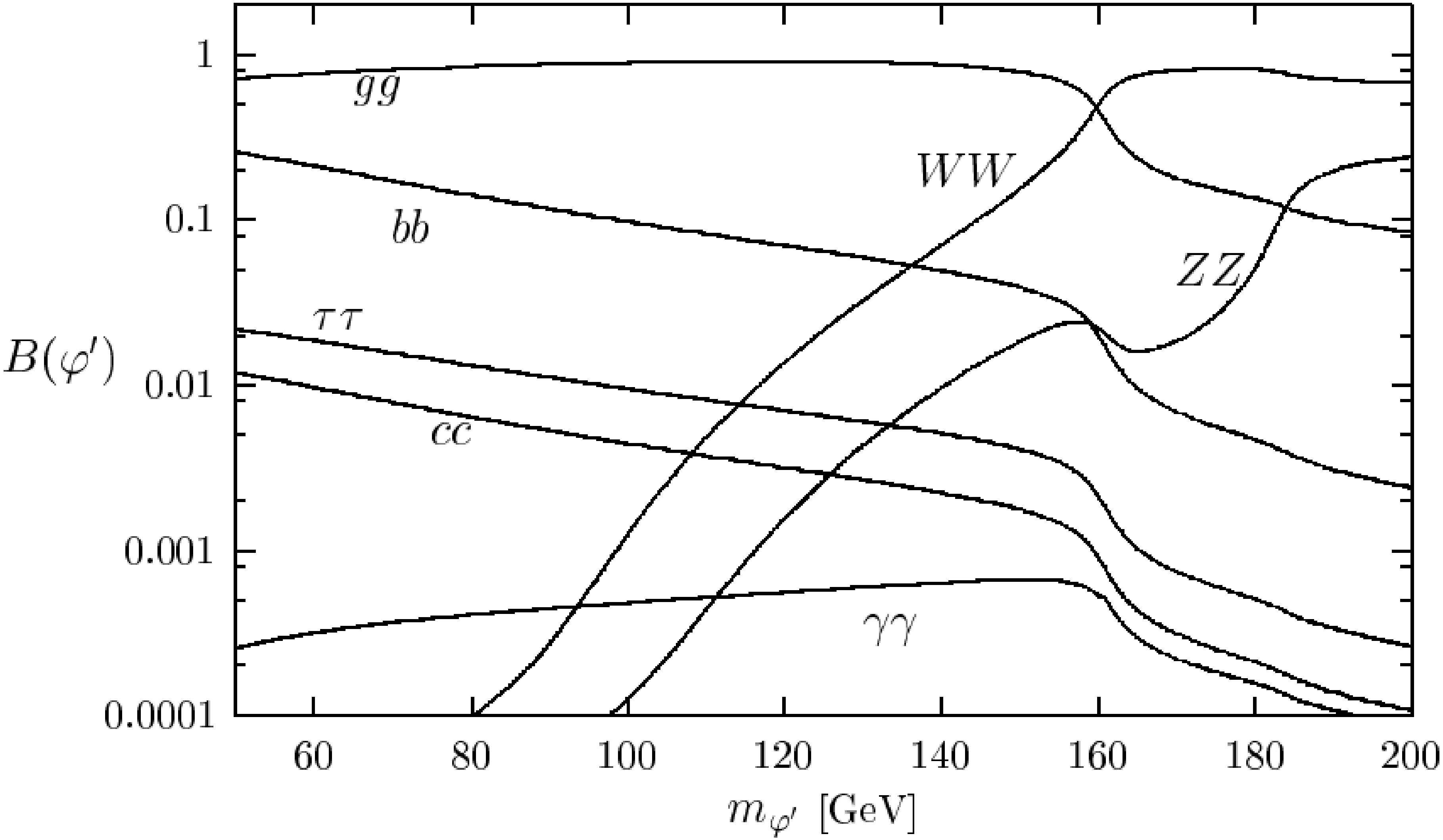
– $\varphi\, gg$ coupling enhanced wrt SM Higgs

– $\varphi\, \gamma\gamma$ coupling suppressed wrt SM Higgs

→ two scalars in the spectrum with modified couplings
compared to the SM Higgs boson

- Randall Sundrum model [Giudice, Rattazzi, Wells '00]

Radion branching ratios, no Higgs-mixing ($\xi = 0$), $\langle \varphi \rangle = 10$ TeV



- TeV^{-1}-sized extra dimensions

example: 5D universal extra dimensions [Appelquist, Cheng, Dobrescu '01]

– all SM particles propagate in the 5th dimension

– mass scale $1/R > 250 - 500\,\mathrm{GeV}$ [Appelquist, Yee '03]

$\rightarrow$ mainly KK-modes n=0, 1, 2 relevant at LHC

– KK-parity conserved: multiplicative quantum number $(-1)^n$

$\rightarrow$ $n = 1$ Higgs-KK-modes can't decay into just SM particles

$\rightarrow$ appearent Higgs sector:

$n = 0$ equivalent to SM Higgs sector

$n = 1$ doesn't look like Higgs

$n = 2$ KK-modes can decay again in $n = 0$-modes

$\rightarrow$ look like heavy Higgs bosons

$\rightarrow$ effective Higgs sector: $h^0, H^0 = h^0_{(2)}, A^0 = G^0_{(2)}, H^\pm = G^\pm_{(2)}$ (like 2HDM)

– scalar sector extensions

• singlet extensions

motivation: the SM Higgs doublet Φ is the only field which can have renormalizable interactions with a hidden, SM-singlet sector:

$$\mathcal{L}_{\text{Higgs-hidden sector int.}} \propto (\Phi^\dagger\Phi)(\phi^{(\dagger)}\phi)_{\text{hidden}}$$

Extension of the SM by ...

... a complex SU(2)-singlet scalar: Higgs sector: H_1^0, H_2^0, A_1^0

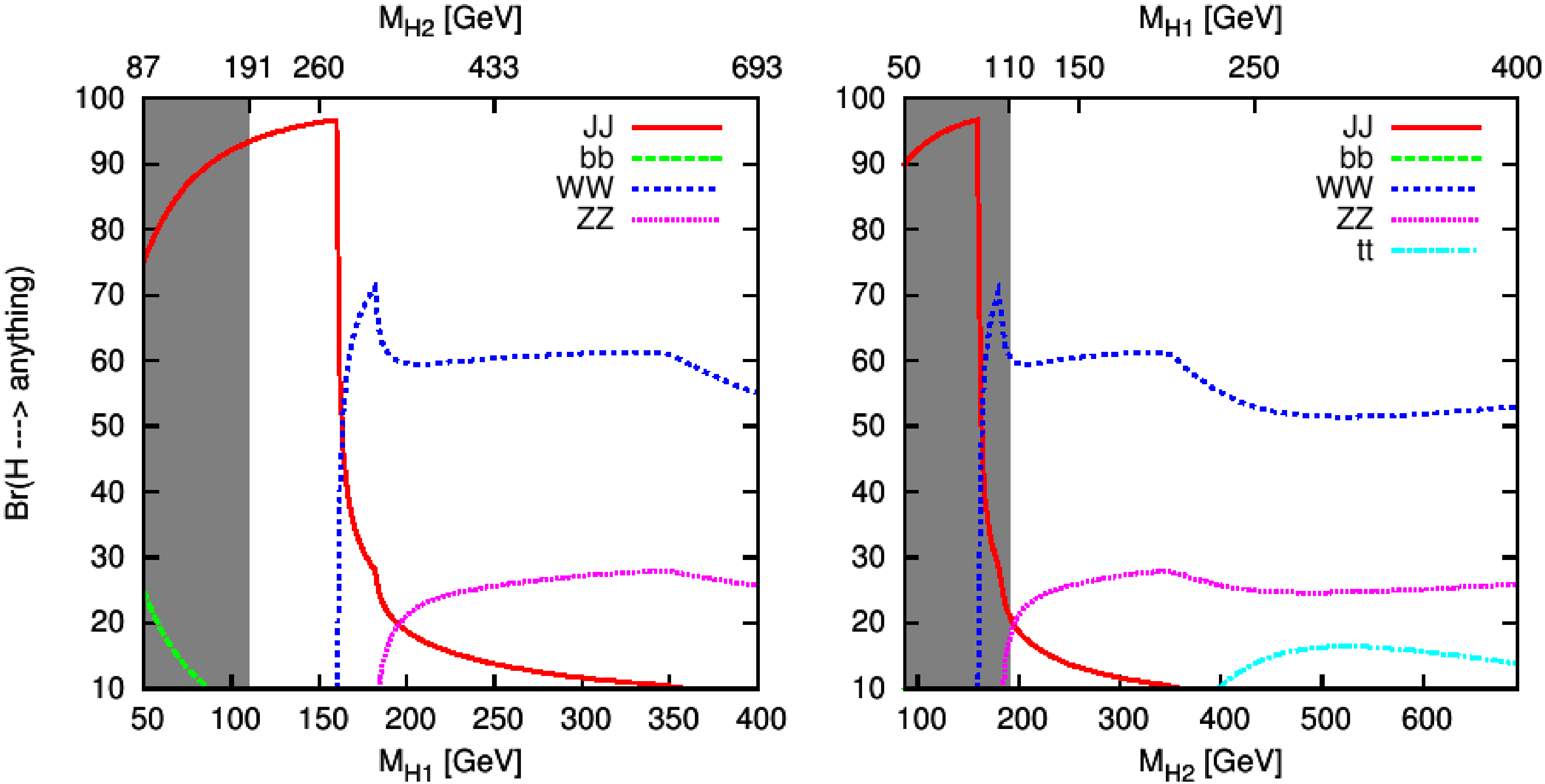
- hidden sector singlet:
  A_1^0 eaten by spontaneously broken $U(1)_{\text{hidden}} \longrightarrow H_1^0, H_2^0$ remain
  [Schabinger, Wells '05,...]
- minimal phantom sector (contains extended neutrino sector):
  global $U(1)$ symmetry broken $\longrightarrow H_1^0, H_2^0, A_1^0 (= J$, massless Goldstone)
  [Cerdeño, Dedes, Underwood '06]

... a real SU(2)-singlet scalar: Higgs sector : H_1^0, H_2^0
[v.d. Bij '06; O'Connell et al. '06; Bahat-Treidel, et al.'06]

consequences for Higgs phenomenology

– mixing of new scalar(s) with ordinary Higgs d.o.f.
– couplings of scalars to SM particles reduced by mixing angles
– potentially large BR(Higgs $\rightarrow$ invisible)
(– singlets as DM candidates)

example: almost invisible decay of lightest Higgs in phantom sector model



[Cerdeño, Dedes, Underwood '06]

– unparticle stuff

- generalities:

The SM is embedded in a theory valid up to a (high) energy scale M_{UV} which contains a sector which becomes conformally invariant at an intermediate scale $\Lambda_U < M_{UV}$ ("unparticle sector") [Georgi '07].

Operators $\mathbf{O}_U$ of this sector have a scaling dimension d_U $(1 < d_U < 2)$.

This conformal invariance is broken once the Higgs acquires a VEV v.
The breaking scale $\Lambda_{\not{U}}$ should be below v, avoiding drastic changes in the Higgs potential.
[Fox, Rajaraman, Shirman '07]

In the conformal regime, the functional form of correlation functions and phase space of the operators $\mathbf{O}_U$ is completely determined by specifying its Lorentz structure (i.e. spin):

→ Propagator: e.g. for scalar $\mathbf{O}_U$: $P_U(p^2) = \frac{A_{d_U}}{2\sin(\pi d_U)} \frac{i}{(-p^2-i\epsilon)^{2-d_U}}$

→ Phase space measure: $d\Phi_U(p) = A_{d_U} \theta(p^0)\theta(p^2)(p^2)^{d_U-2} \frac{d^4p}{(2\pi)^4}$

Energy scales:

high E cut-off $M_{UV} >$ onset of conf. inv. $\Lambda_U >$ EW scale $v >$ conf. breaking $\Lambda_{\not{U}}$

- Higgs bosons & unparticle stuff:

  - Higgs – unparticle mixing [Kikuchi, Okada '07; Delgado et al. '07 & '08]

$$\mathcal{L} \propto \Phi^\dagger \Phi \, \mathbf{O}_U$$

reminiscent of HEIDI models [van der Bij, Dilcher '06 & '07]

  - The Higgs itself belongs to the unparticle sector ("Unhiggs") [Stancato, Terning '08]

$$\mathcal{L} = -\Phi_U^\dagger \left[(D_\mu D^\mu + \mu^2)^{2-d_U} \right] \Phi_U - \left(\frac{\lambda_t}{\Lambda_U^{d_U - 1}} \bar{t}_R \Phi_U^\dagger \begin{pmatrix} t \\ b \end{pmatrix} + \text{h.c.} \right)$$

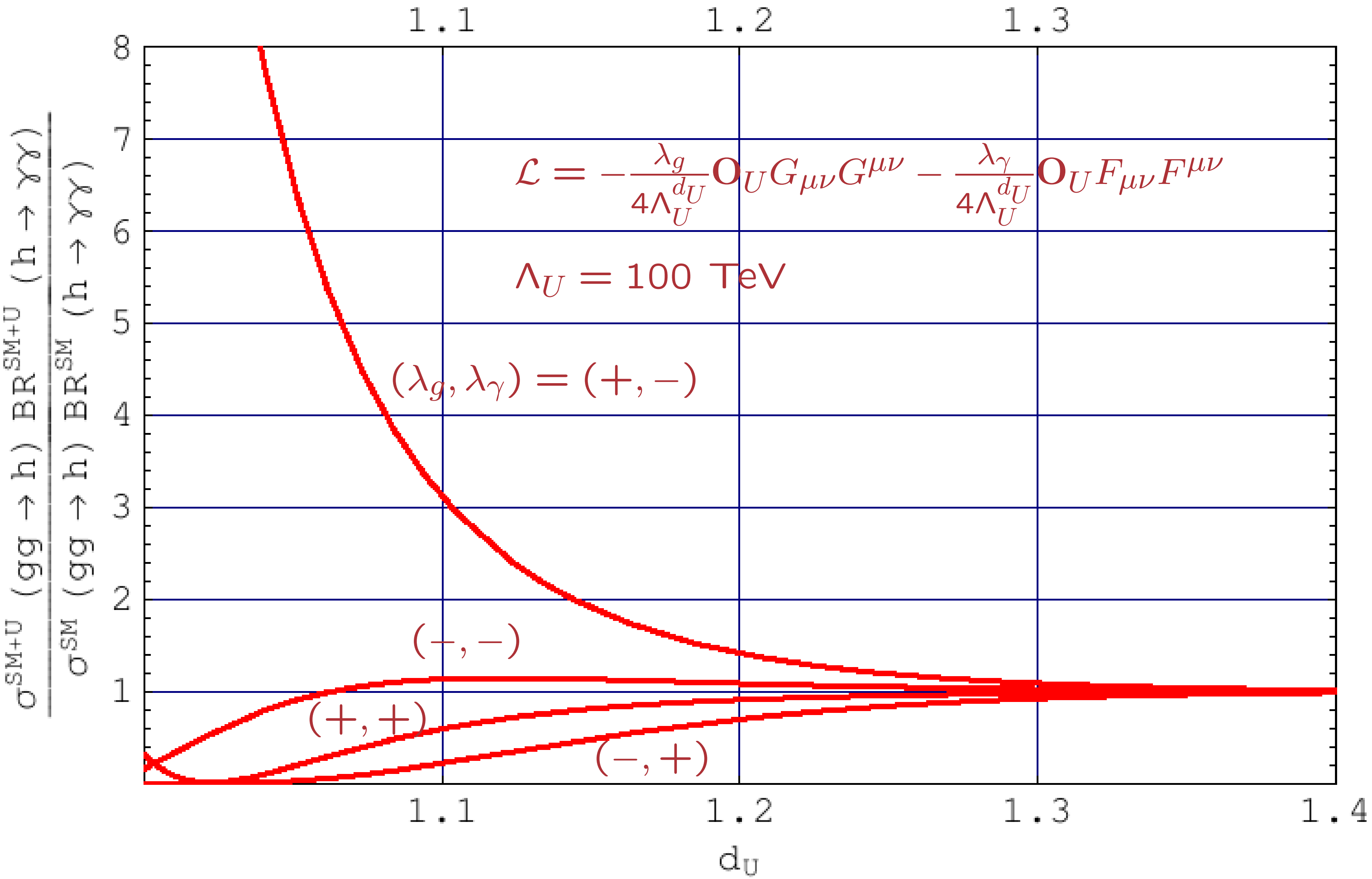
$$- \lambda \left(\frac{\Phi_U^\dagger \Phi_U}{\Lambda_U^{2(d_U-1)}} - \frac{V^2}{2} \right)^2 + \ldots$$

$\rightarrow$ VEV $\langle \Phi_U \rangle = \begin{pmatrix} 0 \\ f(V, \lambda, \mu, \Lambda_U, d_U) \end{pmatrix} =: \begin{pmatrix} 0 \\ \frac{v^{d_U}}{\sqrt{2}} \end{pmatrix}$

• Higgs – unparticle mixing

ratio of $\sigma(pp \to gg \to h \to \gamma\gamma)$: SM+Unparticle effects vs. SM

[Kikuchi, Okada '07]



- Unhiggs

– Unhiggs propagator:

$$\Delta_h(q^2) = -\frac{i}{m^{4-2d_U} - \mu^{4-2d_U} + (\mu^2 - q^2 - i\epsilon)^{2-d_U}} \overset{d_U \to 1}{\longrightarrow} \frac{i}{q^2 - m^2 + i\epsilon}$$

with $m^{4-2d_U} := \frac{2\lambda v^{2d_U}}{\lambda_U^{4d_U-4}} \overset{d_U\to 1}{\longrightarrow} 2\lambda v^2 = m_H$: SM Higgs mass.

Pole at $q^2 = \mu^2 - (\mu^{4-2d_U} - m^{4-2d_U})^{\frac{1}{2-d_U}} =: M^2_{\text{Unh}}$.

– The phase space factor contains a: continuum for $q^2 > \mu^2$,
pole for $q^2 = M^2_{\text{Unh}}$.

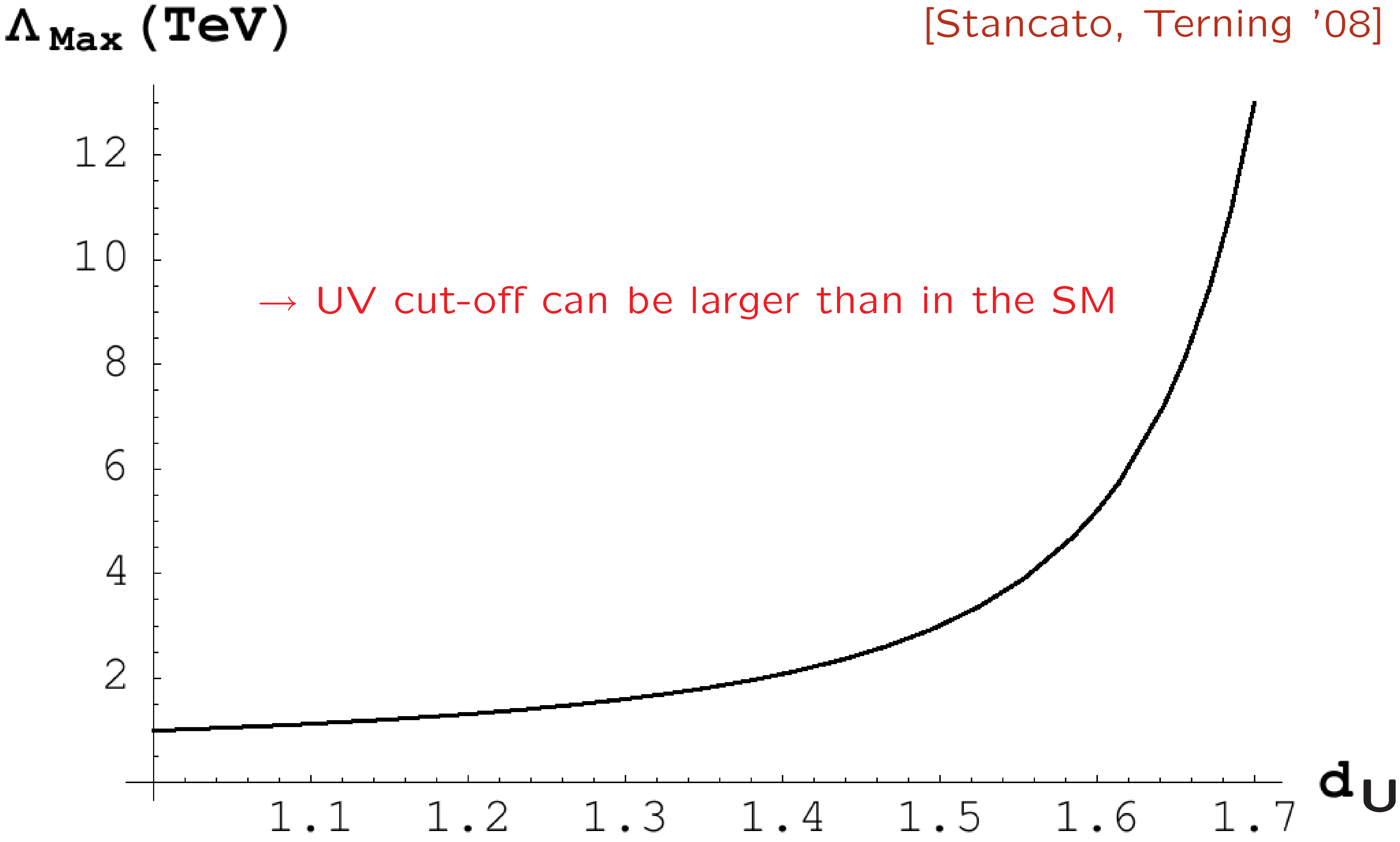
– gauge interaction of Φ_U can be written as non-local using a Wilson line

→ Feynman rules: vertices with arbitrary numbers of gauge bosons

→ WW scattering: positive powers of energy
cancel in tree-level amplitude

- Unhiggs: UV cut-off Λ_{max} from naturalness argument

[Stancato, Terning '08]



→ UV cut-off can be larger than in the SM

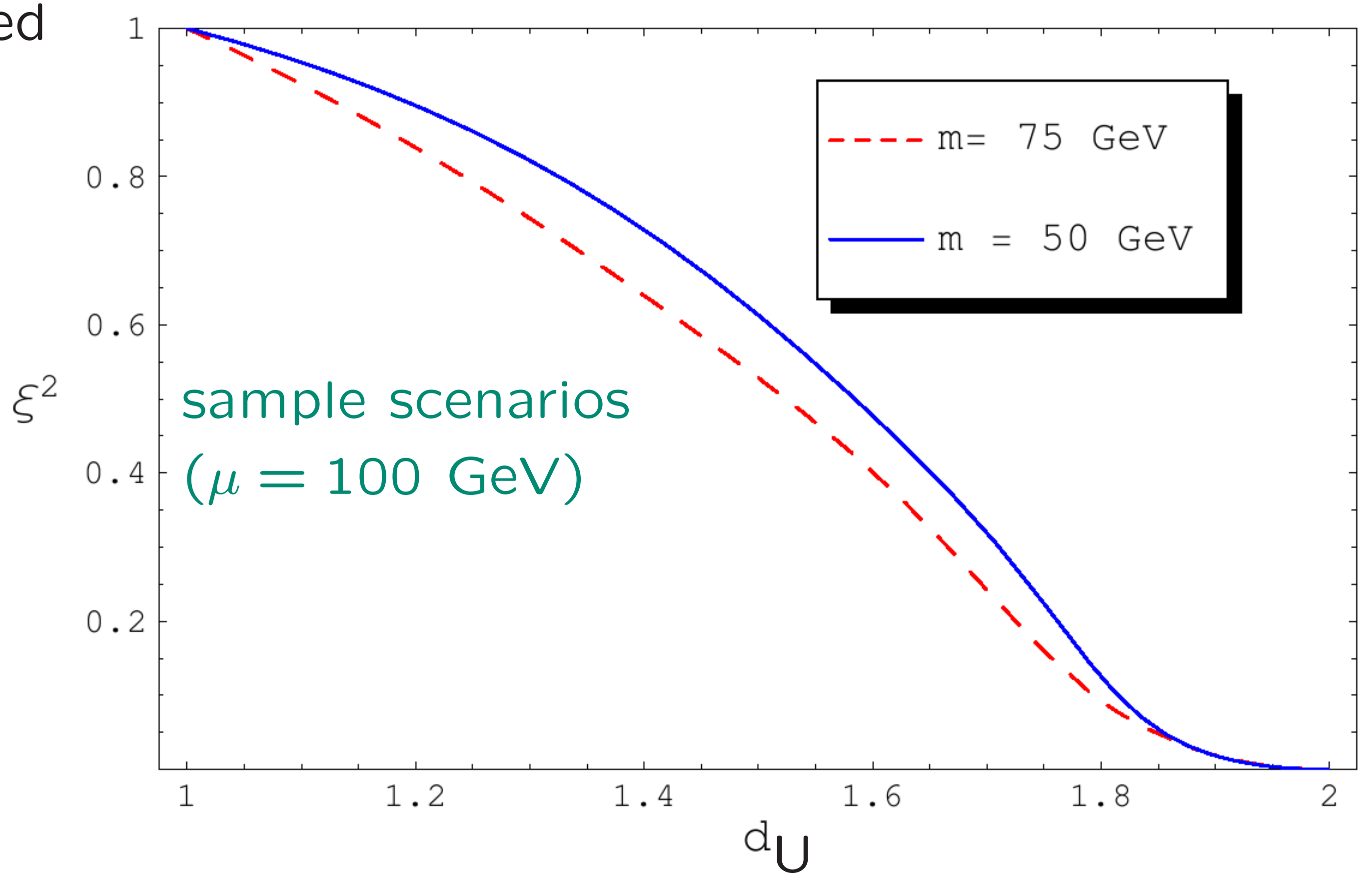
- Unhiggs phenomenology

[Stancato, Terning '08]

  – Higgsstrahlung suppressed

    $$\xi^2 = \frac{\sigma_{\text{Unh}}(e^+e^- \to HZ)}{\sigma_{\text{SM}}(e^+e^- \to HZ)}$$

    gaugephobic for $d_U \to 2$



[Falkowski, Perez-Victoria '09]:

– consistent with electroweak precision observables (S, T)
(even if d_U is not close to 1).

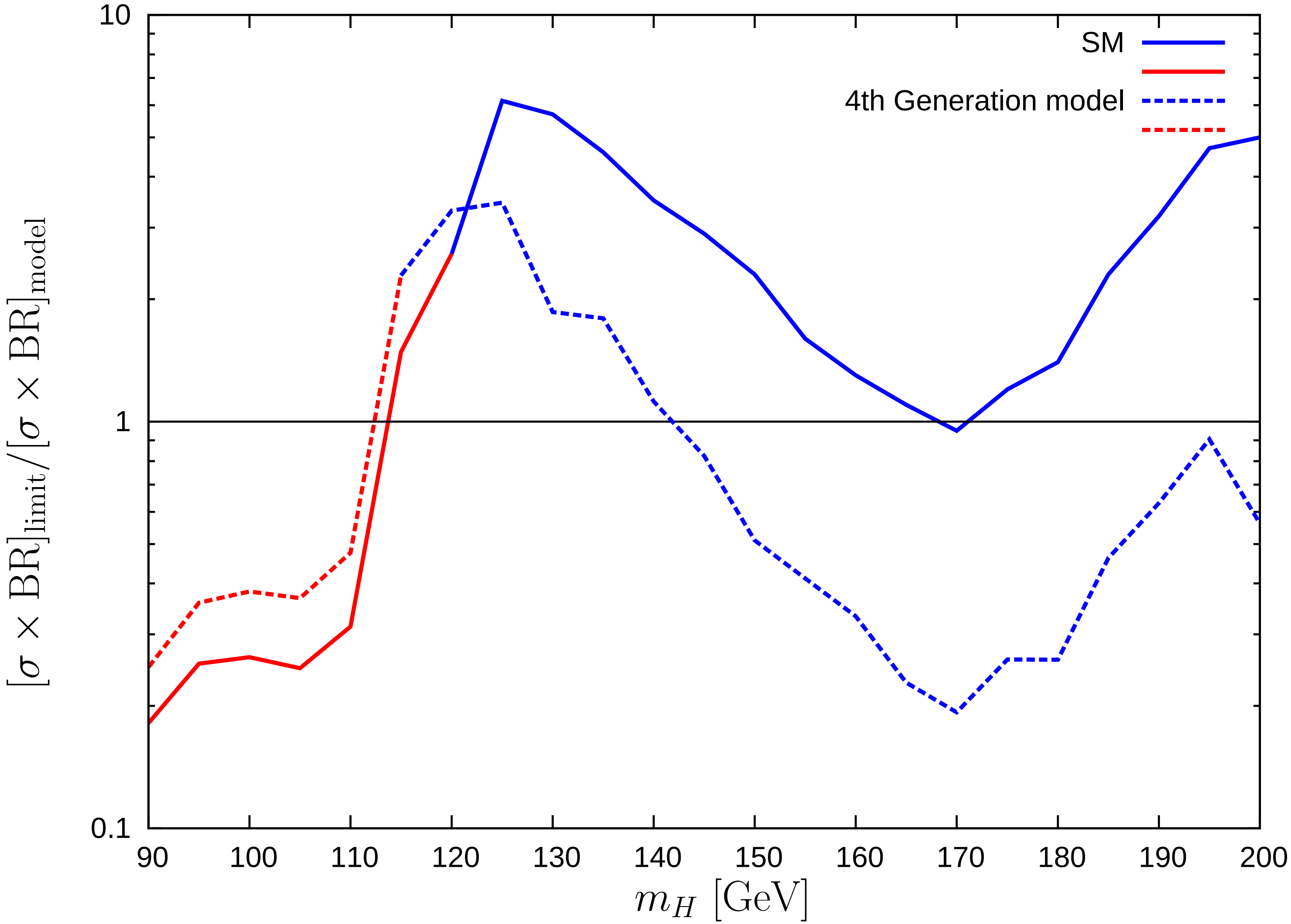
– at the same time Unhiggs signals can be highly suppressed at colliders

→ dedicated LEP analysis needed to determine allowed parameter space

– 4th generation model: SM versus 4th Generation Model exclusion

HiggsBounds : Program for confronting arbitrary Higgs sectors with exclusion bounds from LEP & the Tevatron [Bechtle, Brein, Heinemeyer, Weiglein, Williams '08]

→ www.ippp.dur.ac.uk/HiggsBounds/



summary

- We are sure to observe electroweak symmetry breaking in nature.
  However, up to now, we have no clue how it is realised.
  The Higgs mechanism allows to describe EWSB consistently up to very high energy.

- The Higgs sector may be the portal to new hidden sectors via the (possibly renormalizable) interaction

$$\mathcal{L} \propto \Phi^\dagger \Phi \, \mathbf{O}_{\text{hidden sector}} \, .$$

- We will have to wait and see what the LHC experiments turn out, once the LHC is runnig.
  ... and keep an eye on LEP constraints for new models.