Searching For New Physics

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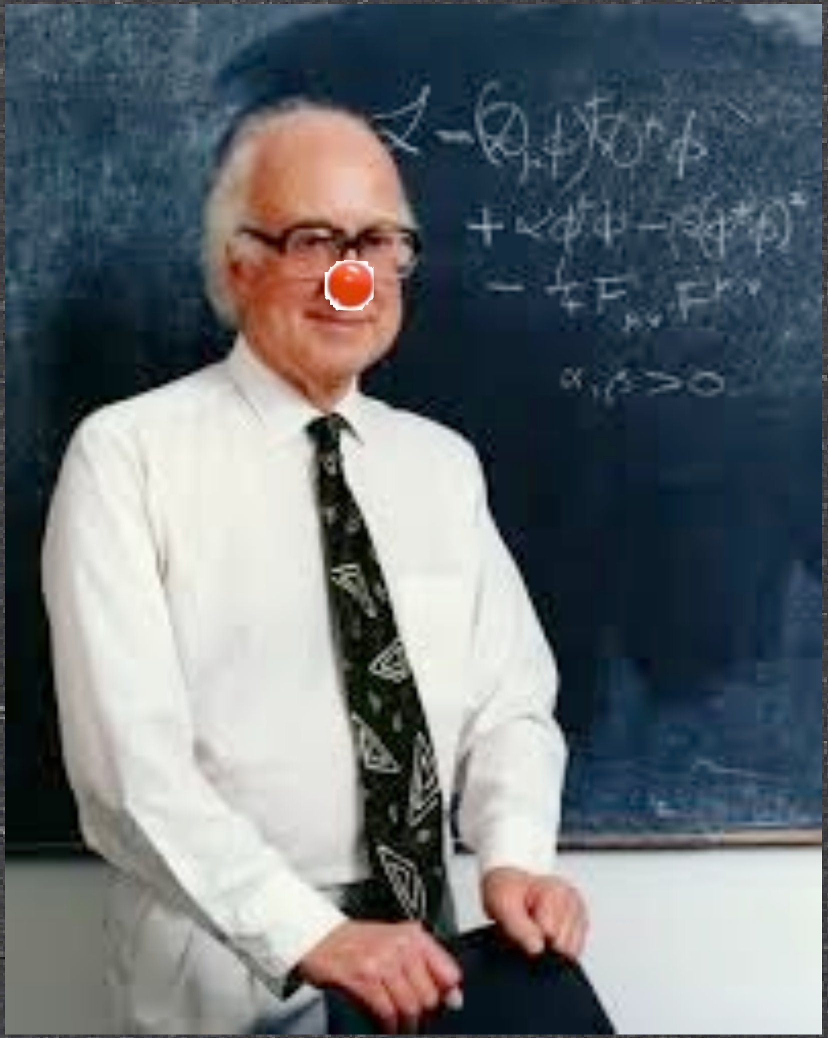


via Exotic Higgs Decays

Osaka, 21 May 2014

Based on oven-fresh paper with R.Vega-Morales 1405.1095,
and some work in progress

Higgs:
where do we stand

Where do we stand

- Gazillion sigma evidence for a SM-like Higgs boson
- Higgs mass is 125.6 GeV, give or take a couple hundred MeV.
- Evidence for coupling both to SM gauge bosons and to fermions
- Evidence for gluon fusion and vector boson fusion production

Simplified Effective Higgs Lagrangian

$$\boxed{\begin{aligned}\mathcal{L}_{h,\mathrm{sim}} = \frac{h}{v}\Big(& \quad 2c_V m_W^2 W_\mu^+ W_\mu^- + c_V m_Z^2 Z_\mu Z_\mu \\ & -c_u \sum_{q=u,c,t} m_q \bar{q} q - c_d \sum_{q=d,s,b} m_q \bar{q} q - c_l \sum_{l=e,\mu\tau} m_l \bar{l} l \\ & + \frac{1}{4} c_{gg} G_{\mu\nu}^a G_{\mu\nu}^a - \frac{1}{4} c_{\gamma\gamma} \gamma_{\mu\nu}\gamma_{\mu\nu} \\ & -\frac{1}{2} c_{WW} W_{\mu\nu}^+ W_{\mu\nu}^- - \frac{1}{4} c_{ZZ} Z_{\mu\nu} Z_{\mu\nu} - \frac{1}{2} c_{Z\gamma} \gamma_{\mu\nu} Z_{\mu\nu} \Big)\end{aligned}}$$

$$c_{WW} = c_{\gamma\gamma} + \frac{c_w}{s_w} c_{Z\gamma} \qquad c_{ZZ} = c_{\gamma\gamma} + \frac{c_w^2 - s_w^2}{c_w s_w} c_{Z\gamma}$$

- Simpler effective theory with 7 free parameters
- <ALL> these parameters are meaningfully constrained by current Higgs data
- Limit of SM+SILH with constraints $\bar{c}_T = \bar{c}_6 = 0 \qquad \bar{c}_{HW} + \bar{c}_{HB} = 0 \qquad \bar{c}_B + \bar{c}_{HB} = 0$
- Standard Model limit: $c_V = c_f = 1$, $c_{gg} = c_{\gamma\gamma} = c_{Z\gamma} = 0$

7 parameter fit

$$c_V = 1.04^{+0.03}_{-0.03}$$

$$c_u = 1.30^{+0.23}_{-0.27}$$

$$c_d = 1.03^{+0.27}_{-0.17}$$

$$c_l = 1.10^{+0.18}_{-0.15}$$

$$c_{gg} = \frac{g_s^2}{16\pi^2}\left(-0.48^{+0.44}_{-0.17}\right)$$

$$c_{\gamma\gamma} = \frac{e^2}{16\pi^2}\left(0.2^{+2.8}_{-3.3}\right)$$

$$c_{Z\gamma} = \frac{e g_L}{\cos\theta_W 16\pi^2}\left(4^{+10}_{-19}\right)$$

using only Higgs data:

$$c_V = 1.03^{+0.08}_{-0.08}$$

Belusca-Maito, AA
arXiv: 1311.1113 + updates

Best fit and 68% CL range for parameters (warning, some errors very non-Gaussian)

Islands of good fit with negative cu, cd, cl ignored here

$\Delta\chi^2 = \chi^2_{SM} - \chi^2_{min} \approx 5.5$, with 7 d.o.f.
SM hypothesis is a perfect fit :-(((

Where do we stand

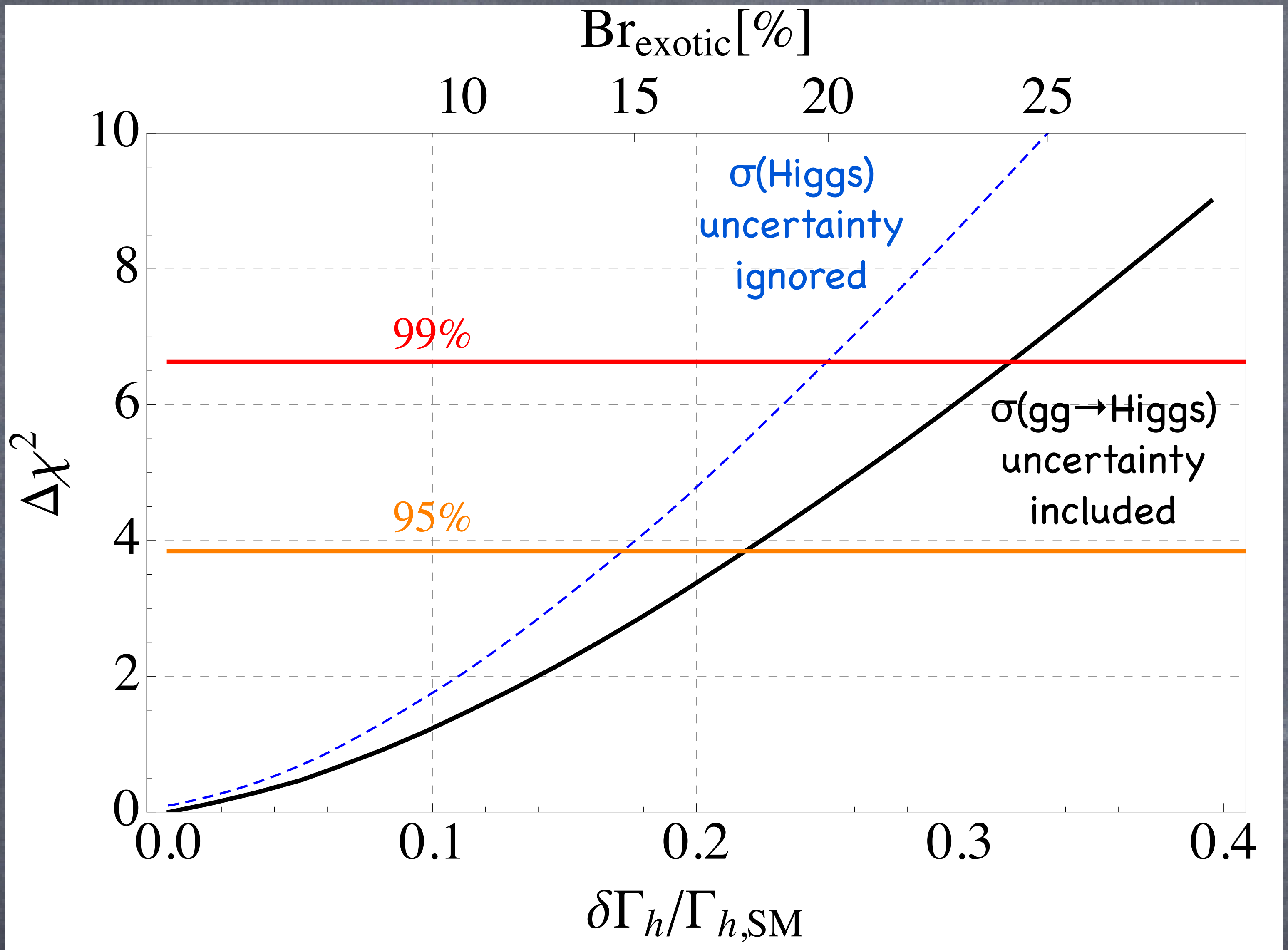
- Higgs is obnoxiously SM-like
- Dimension-6 operators contributing to Higgs couplings suppressed by the scale Λ of order < 1 TeV at most

  c.f. with EWPT probing Λ~10 TeV,
  or B physics probing Λ~100 TeV,
  or Kaon physics probing Λ~10000 TeV

- NP reach will improve in the next LHC run, but not so much in terms of Λ
- However, there is plenty of room for exotic decays not predicted by the SM

Limits on exotic Higgs branching fraction

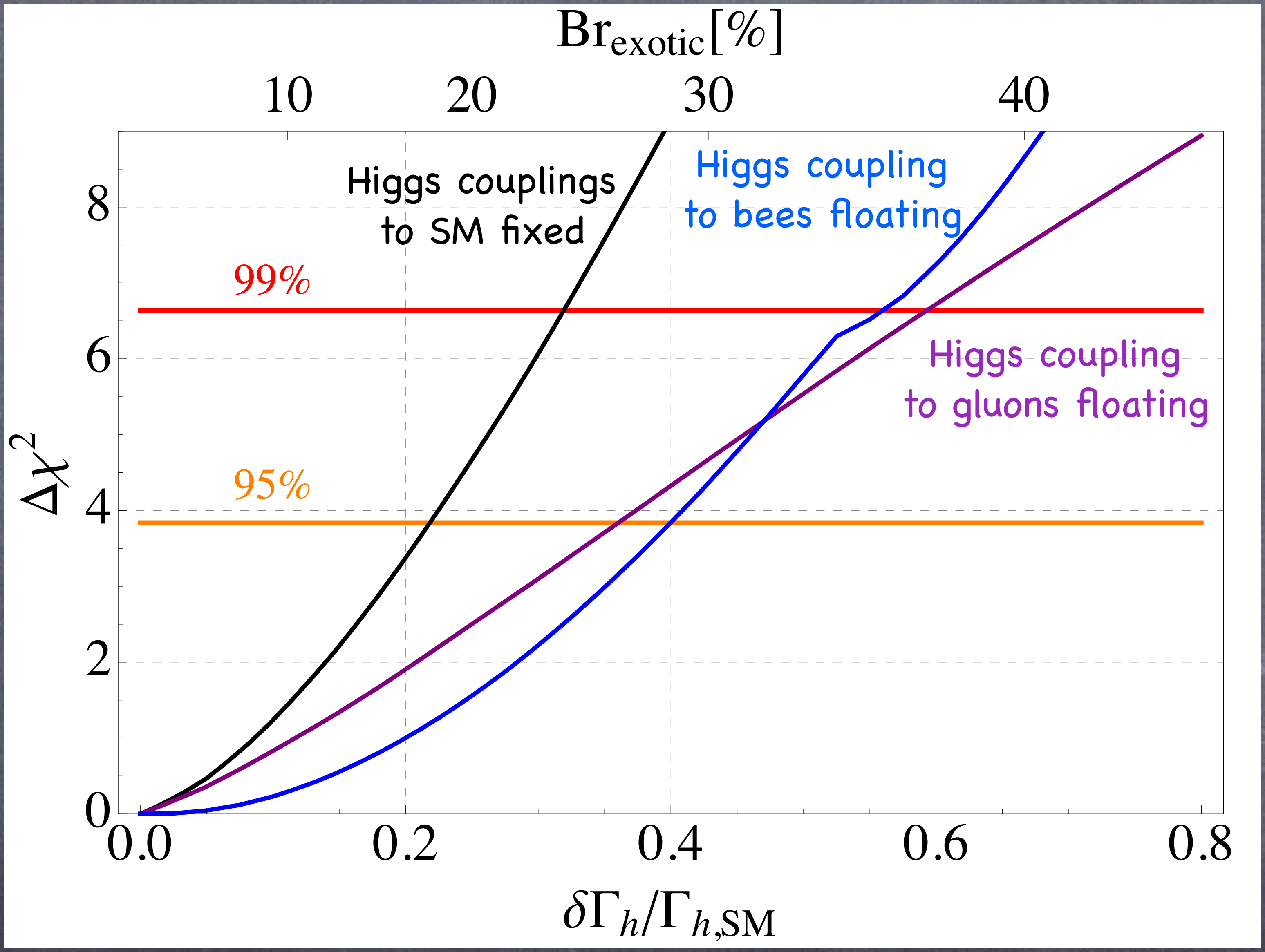
Assuming Higgs couplings to SM fixed



Br(h→exotic) ≲ 18% at 95% CL

Limits on exotic Higgs branching fraction

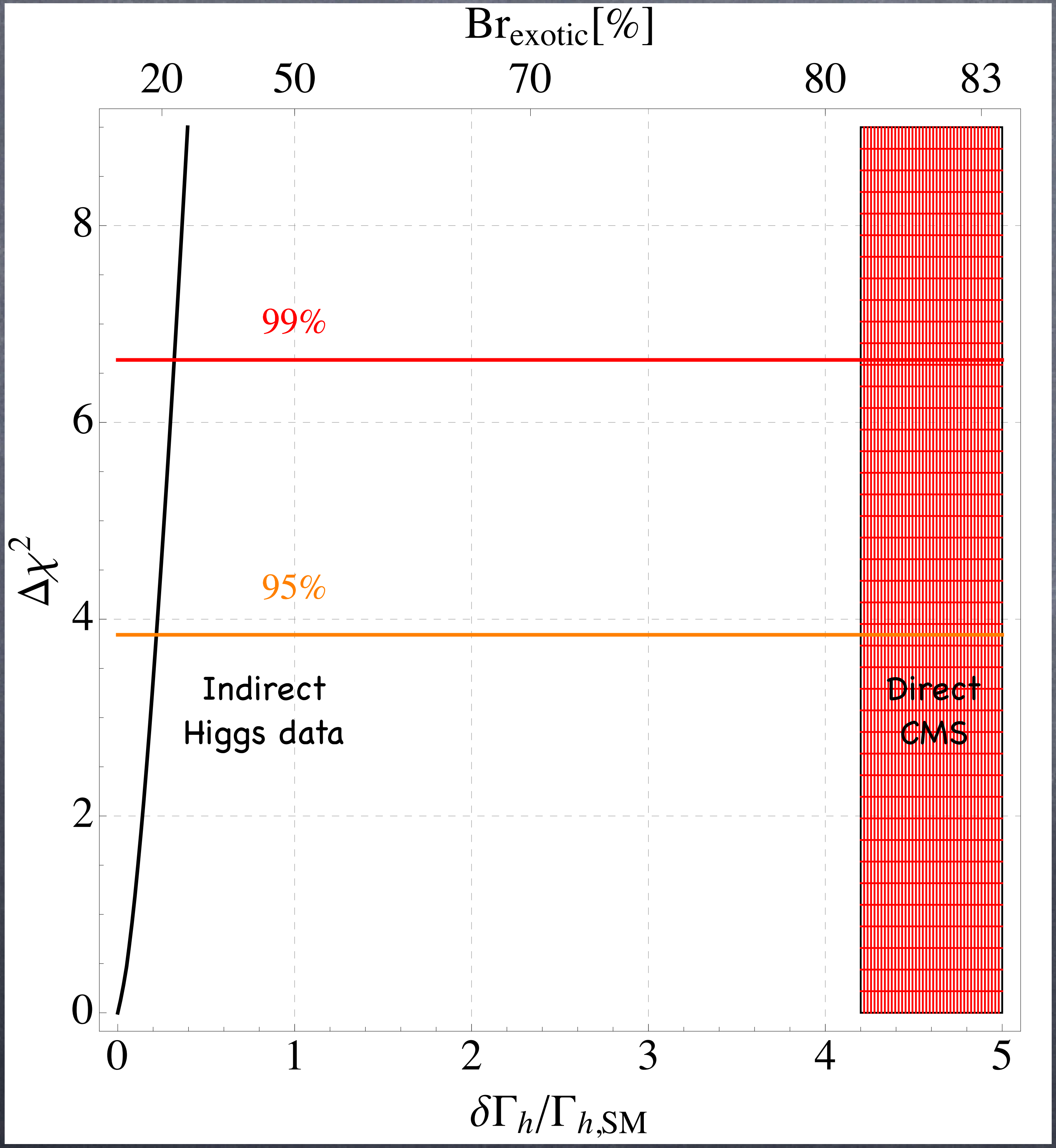
Allowing some Higgs couplings to SM to float



Br(h→exotic) ≲ 30% at 95% CL

Limits on exotic Higgs branching fraction

Compare direct and indirect width constraints



Constraints on additional width

- If all couplings at SM value, exotic branching fraction larger than 18% disfavored at 95% CL
- Allowing new exotic width and, simultaneously, new contributions to Higgs couplings to SM gives even more wiggle room, typically up to 30% exotic branching fraction
- Direct limit on Higgs width from CMS: $\Gamma < 4.2\ \Gamma_{SM}$ @ 95% CL implying exotic branching fractions up to 80%
- If exotic = invisible width, then LHC direct invisible searches place bounds on this parameter space, that are however weaker than indirect ones

Exotic Higgs Decays - Why?

- 18% exotic Higgs branching fraction means that the LHC cross section for exotic Higgs decays could easily be order picobarn
- The SM Higgs width is just 4 MeV, so even weakly coupled new physics can lead to a significant branching fraction for exotic decays. E.g., a new scalar X coupled as $c|H|^2\ |X|^2$ corresponds to $BR(h \to X^* X)=10\%$ BR for $c \sim 0.01$.
- Thanks to the large Higgs cross section even tiny exotic branching fractions may possibly be probed. For spectacular enough signatures we can probe $BR \sim O(10^{-5})$ now and $BR \sim O(10^{-9})$ in the asymptotic future. [Note that the Higgs was first <u>discovered</u> in the diphoton ($BR \sim 10^{-3}$) and 4-lepton ($BR \sim 10^{-4}$) channels]

Exotic Higgs Decays - How?

New light degrees of freedom affecting Higgs decays

No new light degrees of freedom beyond those of the SM

SM+X

HEFT

Multiple possibilities, large model dependence

Leading effects expected from dimension 6 operators beyond the SM

Exotic Higgs Decays: HEFT approach

$$\mathcal{L}_{\rm eff} = \mathcal{L}_{\rm SM} + \mathcal{L}_{d=5} + \mathcal{L}_{d=6} + \dots$$

$$\mathcal{L}_{d=6} = \mathcal{L}_{\rm SILH} + \mathcal{L}_{\rm 2FV} + \mathcal{L}_{\rm 2FD} + \mathcal{L}_{\rm 4F} + \mathcal{L}_{\rm Gauge} + \mathcal{L}_{\rm CPB}$$

Higgs interactions with itself, SM gauge bosons and Yukawa interactions with fermions

$$\begin{aligned}
&\frac{\bar{c}_H}{2v^2}\partial^\mu(H^\dagger H)\partial_\mu(H^\dagger H) + \frac{\bar{c}_T}{2v^2}\left(H^\dagger \overleftrightarrow{D}^\mu H\right)\left(H^\dagger \overleftrightarrow{D}_\mu H\right) - \frac{\bar{c}_6\lambda}{v^2}(H^\dagger H)^3 \\
&+ \left(\left(\frac{\bar{c}_u}{v^2} y_u H^\dagger H\, \bar{q}_L H^c u_R + \frac{\bar{c}_d}{v^2} y_d H^\dagger H\, \bar{q}_L H d_R + \frac{\bar{c}_l}{v^2} y_l H^\dagger H\, \bar{L}_L H l_R\right) + h.c.\right) \\
&+ \frac{i\bar{c}_W g}{2m_W^2}\left(H^\dagger \sigma^i \overleftrightarrow{D}^\mu H\right)(D^\nu W_{\mu\nu})^i + \frac{i\bar{c}_B g'}{2m_W^2}\left(H^\dagger \overleftrightarrow{D}^\mu H\right)(\partial^\nu B_{\mu\nu}) \\
&+ \frac{i\bar{c}_{HW} g}{m_W^2}(D^\mu H)^\dagger \sigma^i (D^\nu H) W^i_{\mu\nu} + \frac{i\bar{c}_{HB} g'}{m_W^2}(D^\mu H)^\dagger (D^\nu H) B_{\mu\nu} \\
&+ \frac{\bar{c}_\gamma g'^2}{m_W^2} H^\dagger H B_{\mu\nu} B^{\mu\nu} + \frac{\bar{c}_g g_S^2}{m_W^2} H^\dagger H G^a_{\mu\nu} G^{a\mu\nu},
\end{aligned}$$

2-fermion vertex corrections

$$\begin{aligned}
&\frac{i\bar{c}_{Hq}}{v^2}(\bar{q}_L\gamma^\mu q_L)\left(H^\dagger \overleftrightarrow{D}_\mu H\right) + \frac{i\bar{c}'_{Hq}}{v^2}(\bar{q}_L\gamma^\mu \sigma^i q_L)\left(H^\dagger \sigma^i \overleftrightarrow{D}_\mu H\right) \\
&+ \frac{i\bar{c}_{Hu}}{v^2}(\bar{u}_R\gamma^\mu u_R)\left(H^\dagger \overleftrightarrow{D}_\mu H\right) + \frac{i\bar{c}_{Hd}}{v^2}(\bar{d}_R\gamma^\mu d_R)\left(H^\dagger \overleftrightarrow{D}_\mu H\right) \\
&+ \left(\frac{i\bar{c}_{Hud}}{v^2}(\bar{u}_R\gamma^\mu d_R)\left(H^{c\,\dagger} \overleftrightarrow{D}_\mu H\right) + h.c.\right) \\
&+ \frac{i\bar{c}_{HL}}{v^2}(\bar{L}_L\gamma^\mu L_L)\left(H^\dagger \overleftrightarrow{D}_\mu H\right) + \frac{i\bar{c}'_{HL}}{v^2}(\bar{L}_L\gamma^\mu \sigma^i L_L)\left(H^\dagger \sigma^i \overleftrightarrow{D}_\mu H\right) \\
&+ \frac{i\bar{c}_{Hl}}{v^2}(\bar{l}_R\gamma^\mu l_R)\left(H^\dagger \overleftrightarrow{D}_\mu H\right),
\end{aligned}$$

2-fermion dipole operators

$$\begin{aligned}
&\frac{\bar{c}_{uB} g'}{m_W^2} y_u \bar{q}_L H^c \sigma^{\mu\nu} u_R B_{\mu\nu} + \frac{\bar{c}_{uW} g}{m_W^2} y_u \bar{q}_L \sigma^i H^c \sigma^{\mu\nu} u_R W^i_{\mu\nu} + \frac{\bar{c}_{uG} g_S}{m_W^2} y_u \bar{q}_L H^c \sigma^{\mu\nu} \lambda^a u_R G^a_{\mu\nu} \\
&+ \frac{\bar{c}_{dB} g'}{m_W^2} y_d \bar{q}_L H \sigma^{\mu\nu} d_R B_{\mu\nu} + \frac{\bar{c}_{dW} g}{m_W^2} y_d \bar{q}_L \sigma^i H \sigma^{\mu\nu} d_R W^i_{\mu\nu} + \frac{\bar{c}_{dG} g_S}{m_W^2} y_d \bar{q}_L H \sigma^{\mu\nu} \lambda^a d_R G^a_{\mu\nu} \\
&+ \frac{\bar{c}_{lB} g'}{m_W^2} y_l \bar{L}_L H \sigma^{\mu\nu} l_R B_{\mu\nu} + \frac{\bar{c}_{lW} g}{m_W^2} y_l \bar{L}_L \sigma^i H \sigma^{\mu\nu} l_R W^i_{\mu\nu} + h.c.
\end{aligned}$$

4-fermion operators

Gauge boson self-interactions

CP Violating interactions

$$\begin{aligned}
&\frac{i\tilde{c}_{HW} g}{m_W^2}(D^\mu H)^\dagger \sigma^i (D^\nu H)\tilde{W}^i_{\mu\nu} + \frac{i\tilde{c}_{HB} g'}{m_W^2}(D^\mu H)^\dagger (D^\nu H)\tilde{B}_{\mu\nu} \\
&+ \frac{\tilde{c}_\gamma g'^2}{m_W^2} H^\dagger H B_{\mu\nu}\tilde{B}^{\mu\nu} + \frac{\tilde{c}_g g_S^2}{m_W^2} H^\dagger H G^a_{\mu\nu}\tilde{G}^{a\mu\nu} \\
&+ \frac{\tilde{c}_{3W} g^3}{m_W^2}\epsilon^{ijk} W^{i\,\nu}_{\mu} W^{j\,\rho}_{\nu} \tilde{W}^{k\,\mu}_{\rho} + \frac{\tilde{c}_{3G} g_S^3}{m_W^2} f^{abc} G^{a\,\nu}_{\mu} G^{b\,\rho}_{\nu} \tilde{G}^{c\,\mu}_{\rho},
\end{aligned}$$

2499 ways to leave your lover Alonso,Jenkins,Manohar,Trott 1312.2014

Some operators probed by EW precision tests,
some by Higgs coupling measurements,
and some by exotic Higgs decays

for exotic decays part,
work in progress
with F.Arnardi, and H. Belusca

Exotic Higgs Decays

This talk:

- Exotic Higgs decays in the golden channel
  AA,Vega-Morales, 1405.1095
- Maybe: exotic Higgs decays in the composite Higgs scenario
  AA,Straub,Vicente, 1312.5329

For much more see the Snowmass review

Curtin et al, 1312.4992

Exotic Higgs Decays
in the golden channel

Exotic Decays in the golden channel

- Study the reach of the golden channel to exotic Higgs decays using the matrix element methods
- Previously, analogous methods used for Higgs couplings extraction

Stolarski,Vega-Morales, 1208.4840

Chen,Tran,Vega-Morales, 1211.1959

Chen,Vega-Morales, 1310.2893

Chen et al. 1401.2077

Exotic Decays in the golden channel

Procedure

- Compute fully differential decay width for h→4l process, including SM +NP interference
- Use this as event-by-event probability density function
- Out of this PDF, construct likelihood function for dataset with N events
- Construct likelihood ratio of SM vs NP hypothesis
- Generate multiple sets of N events for both hypotheses to find expected distribution of L(λ) and Λ

$$\mathcal{P}_S(m_h^2, M_1, M_2, \vec{\Omega}|\vec{\lambda}) = \frac{d\Gamma_{h\to 4\ell}}{dM_1^2 dM_2^2 d\vec{\Omega}}.$$

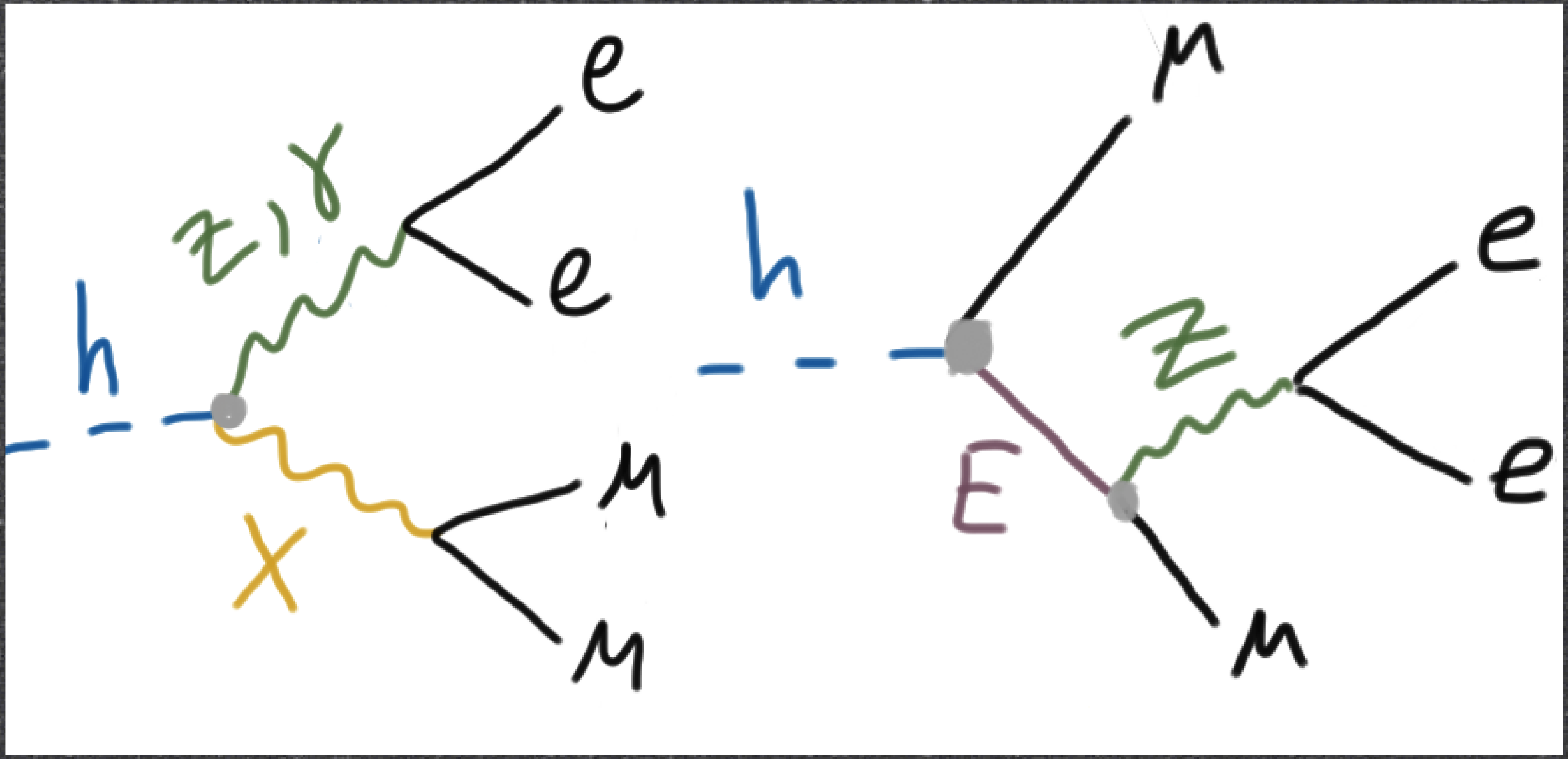
$$L(\vec{\lambda}) = \prod^N \mathcal{P}_S(\mathcal{O}|\vec{\lambda}).$$

$$\Lambda = 2\log[\mathcal{L}(\vec{\lambda}_1)/\mathcal{L}(\vec{\lambda}_2)]$$

Exotic Decays in the golden channel

2 models studied here

- Light hidden photon X mixing with the Z boson via the hypercharge portal
- Light charged vector-like lepton E mixing with SM electron or muon



Hidden Photon
in the golden channel

Hidden photon model

Hidden photon X talking to SM vie hypercharge portal

$$\mathcal{L} = \mathcal{L}_{\rm SM} - \frac{1-\epsilon^2\cos^{-2}\theta_W}{4}\hat{X}_{\mu\nu}\hat{X}_{\mu\nu} + \frac{1}{2}\hat{m}_X^2\hat{X}_\mu\hat{X}_\mu + \frac{\epsilon}{2\cos\theta_W}B_{\mu\nu}\hat{X}_{\mu\nu}$$

One consequence of mixing: hidden photon couples to matter

$$g_{X,f} = \epsilon\, e\left[Q_f\left(1-\frac{\tan^2\theta_W m_X^2}{m_Z^2-m_X^2}\right)+T_f^3\frac{m_X^2}{\cos^2\theta_W(m_Z^2-m_X^2)}\right].$$

For small mass it mili-couples to electric current
(hence hidden photon)

Another consequence of mixing: hidden photon mixes with Z boson

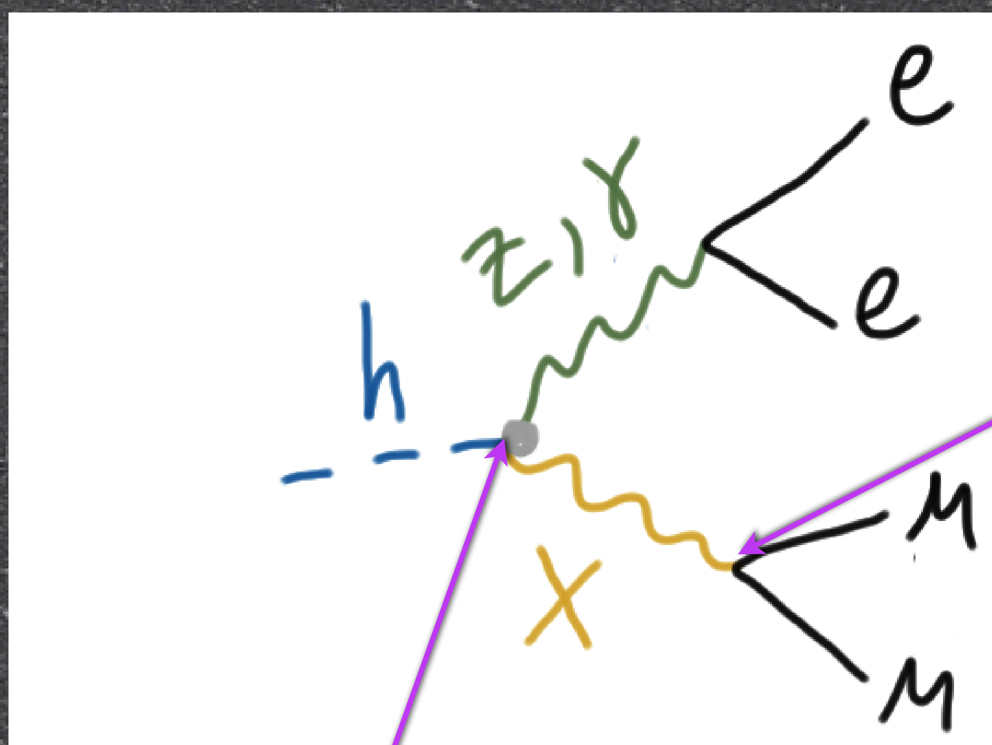
$$\hat{Z}_\mu = \cos\alpha Z_\mu + \sin\alpha X_\mu, \qquad \hat{X}_\mu = -\sin\alpha Z_\mu + \cos\alpha X_\mu, \qquad \alpha\approx\epsilon\tan\theta_W\frac{m_Z^2}{m_Z^2-m_X^2}+\mathcal{O}(\epsilon^2)$$

Therefore it couples to Higgs

$$\mathcal{L}_{hZX} = c_{hZX}\frac{m_Z^2}{v}hZ_\mu X_\mu, \qquad c_{hZX} = \frac{2\epsilon\tan\theta_W m_X^2}{m_Z^2-m_X^2}+\mathcal{O}(\epsilon^2).$$

Hidden photon in the golden channel

Higgs can decay as h → Z X → 4l!



$$g_{X,\ell} X_\mu \bar{\ell} \gamma_\mu \ell$$

$$c_{hZX} \frac{m_Z^2}{v} h Z_\mu X_\mu$$

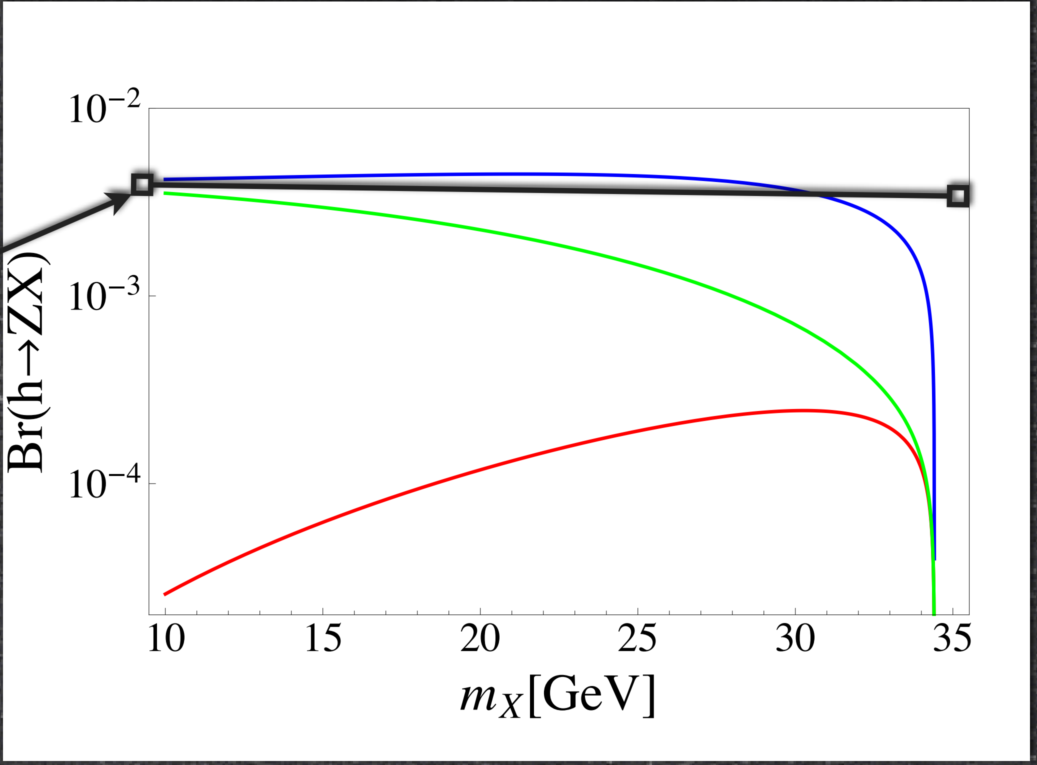
Hidden photon - constraints from 4l

Event count in the h → 4l channel

Channel	4e	2e2μ	4μ	4l
ZZ background	1.1 ± 0.1	3.2 ± 0.2	2.5 ± 0.2	6.8 ± 0.3
Z + X background	0.8 ± 0.2	1.3 ± 0.3	0.4 ± 0.2	2.6 ± 0.4
All backgrounds	1.9 ± 0.2	4.6 ± 0.4	2.9 ± 0.2	9.4 ± 0.5
m_H = 125 GeV	3.0 ± 0.4	7.9 ± 1.0	6.4 ± 0.7	17.3 ± 1.3
m_H = 126 GeV	3.4 ± 0.5	9.0 ± 1.1	7.2 ± 0.8	19.6 ± 1.5
Observed	4	13	8	25

$$\frac{\Delta\Gamma_{h\to 4\mu}}{\Gamma^{\rm SM}_{h\to 4\mu}} < 0.90, \qquad \frac{\Delta\Gamma_{h\to 2e2\mu}}{\Gamma^{\rm SM}_{h\to 2e2\mu}} < 0.83, \qquad \frac{\Delta\Gamma_{h\to 4e}}{\Gamma^{\rm SM}_{h\to 4e}} < 1.27,$$

$$\frac{\Delta\Gamma_{h\to 4\ell}}{\Gamma^{\rm SM}_{h\to 4\ell}} < 0.52.$$



Hidden photon in the golden channel

Kinetic mixing with hidden photon affects Z mass and Z couplings to matter

$$m_Z^2 = \hat{m}_Z^2 + \epsilon^2 \frac{\tan^2\theta_W \hat{m}_Z^4}{m_Z^2 - \hat{m}_X^2} + \mathcal{O}(\epsilon^3),$$

$$g_{Z,f} = \hat{g}_{Z,f}\left(1 - \epsilon^2 \frac{\tan^2\theta_W m_Z^4}{(m_Z^2 - m_X^2)^2}\right) - \epsilon^2 \sqrt{g_L^2 + g_Y^2}\frac{\tan^2\theta_W m_Z^2}{m_Z^2 - m_X^2} Y_f,$$

Fitting to LEP-1 and W mass data

$$|\epsilon| \lesssim 0.024 \sqrt{1 - \frac{m_X^2}{m_Z^2}} \qquad \text{at } 95\% \text{ C.L.},$$

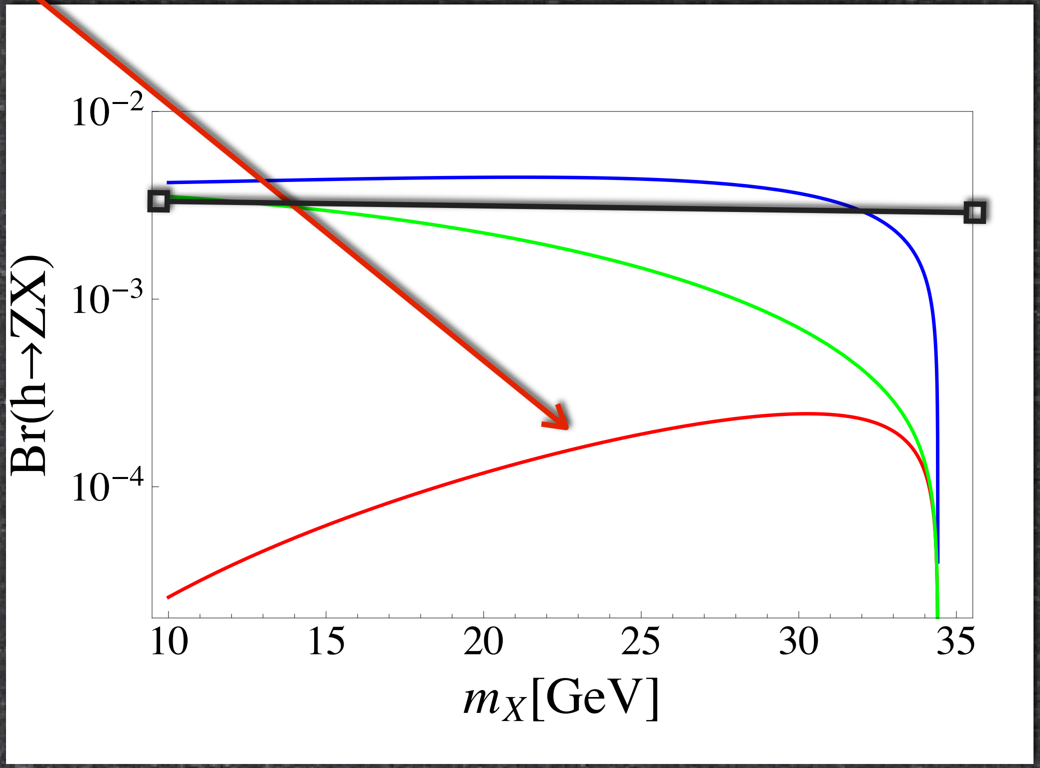
Hidden photon in the golden channel

Electroweak Precision Observables imply

$$|\epsilon| \lesssim 0.024 \sqrt{1 - \frac{m_X^2}{m_Z^2}} \qquad \text{at } 95\% \text{ C.L.},$$

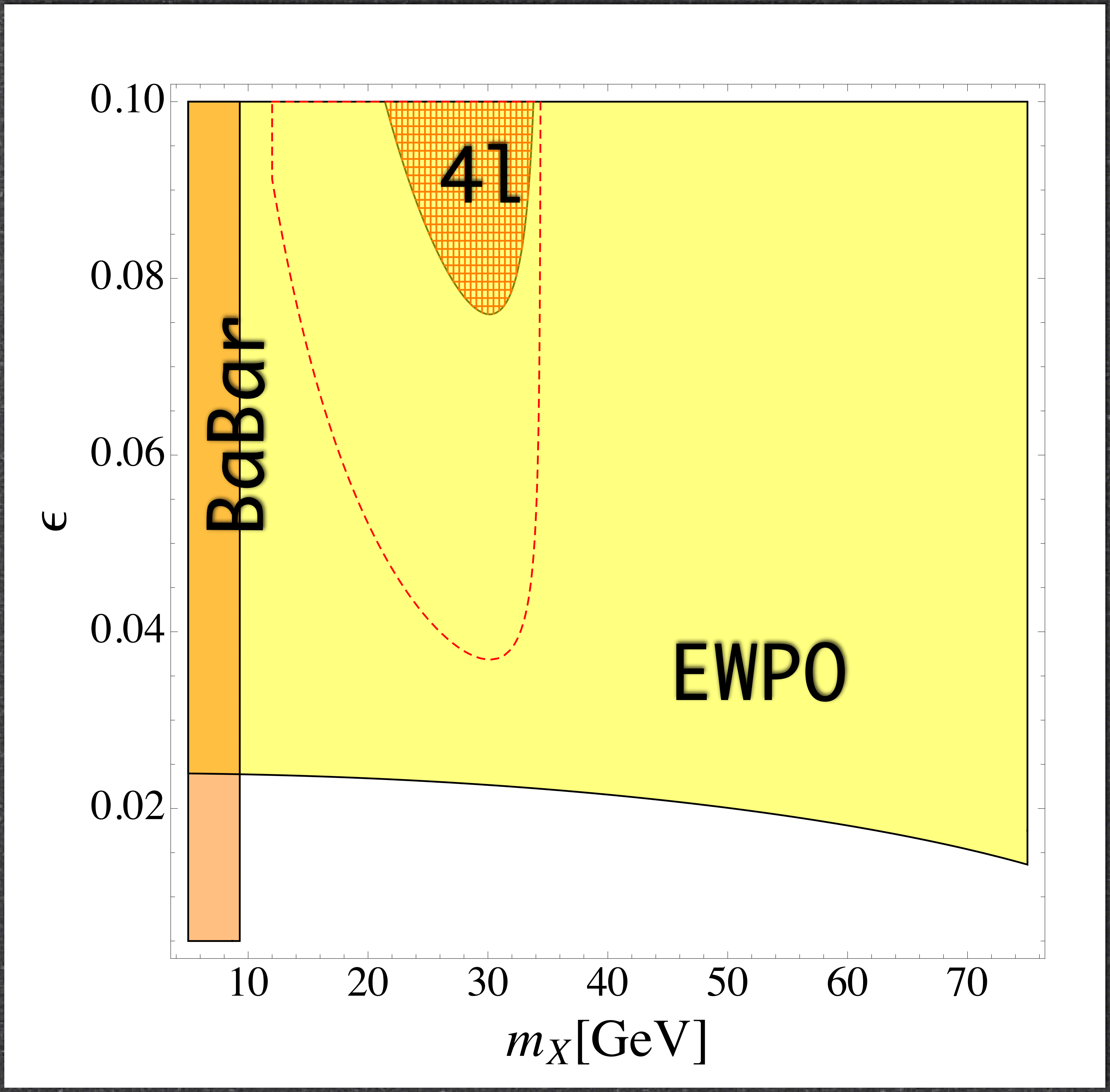
for 10 GeV < mX < mZ, and stronger bounds below from B-factories

Follows the bound on branching fraction h → Z X



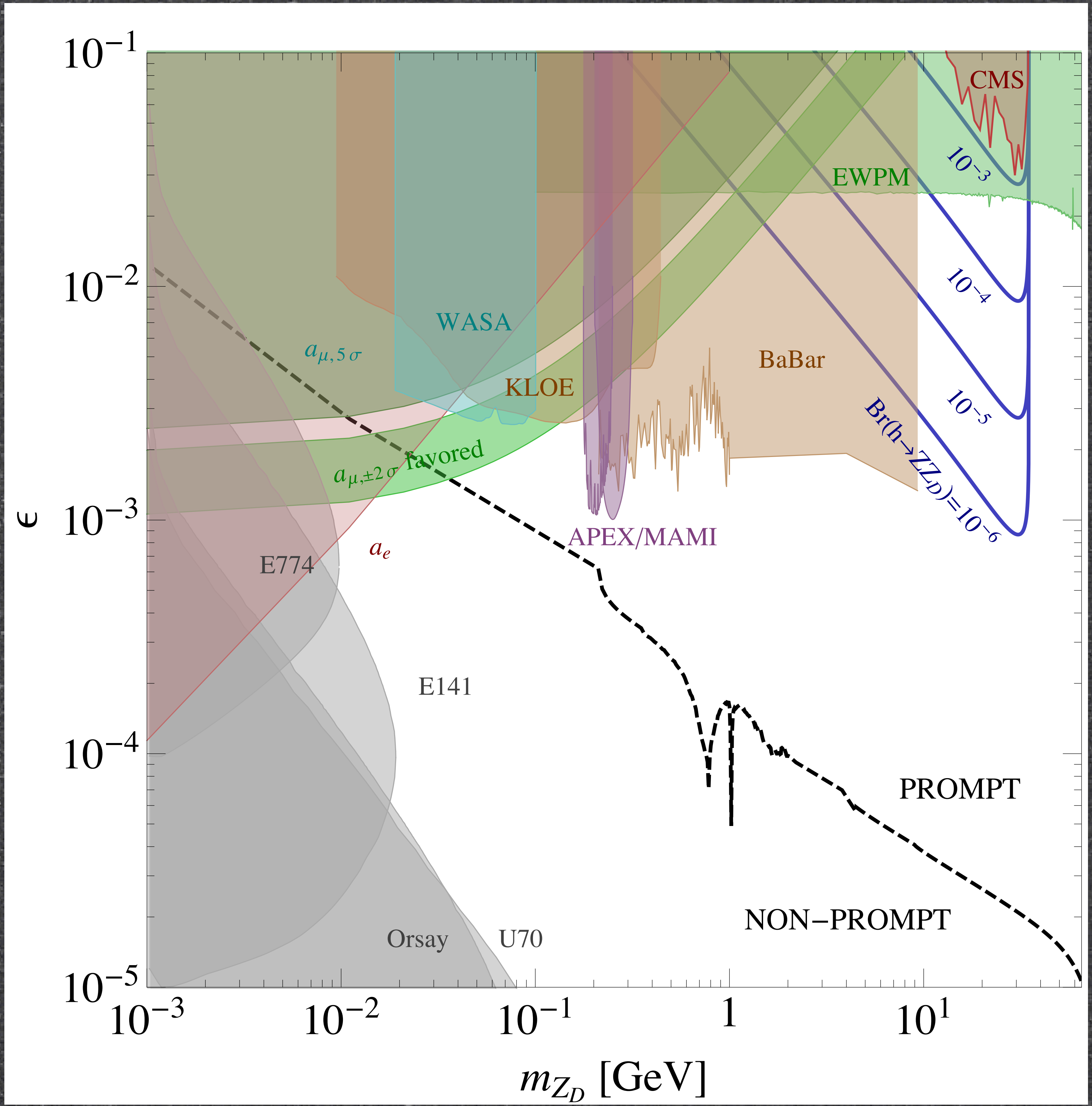
Hidden photon - constraints from 4l

Parameter Space



Hidden photon - constraints from 4l

Larger Parameter Space



Curtin et al, 1312.4992

Hidden photon in the golden channel

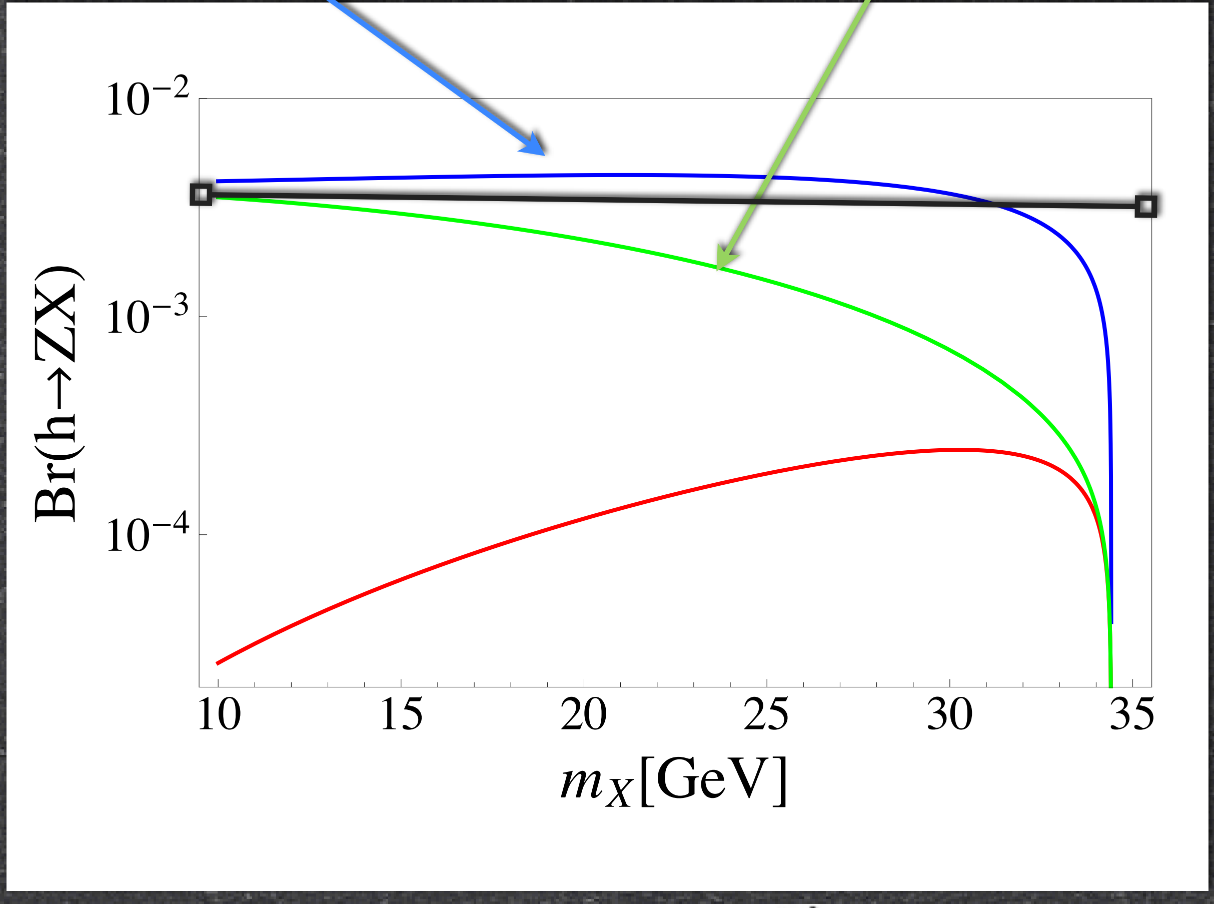
Simple modification of hidden photon model

$$\Delta\mathcal{L} = \frac{\epsilon_2}{\cos\theta_W}\left(\frac{|H|^2}{v^2} - \frac{1}{2}\right) B_{\mu\nu}\hat{X}_{\mu\nu} + \frac{\epsilon_3}{\cos\theta_W}\frac{|H|^2}{v^2}\tilde{B}_{\mu\nu}\hat{X}_{\mu\nu},$$

$\varepsilon_2=0.02$

$\varepsilon_3=0.02$

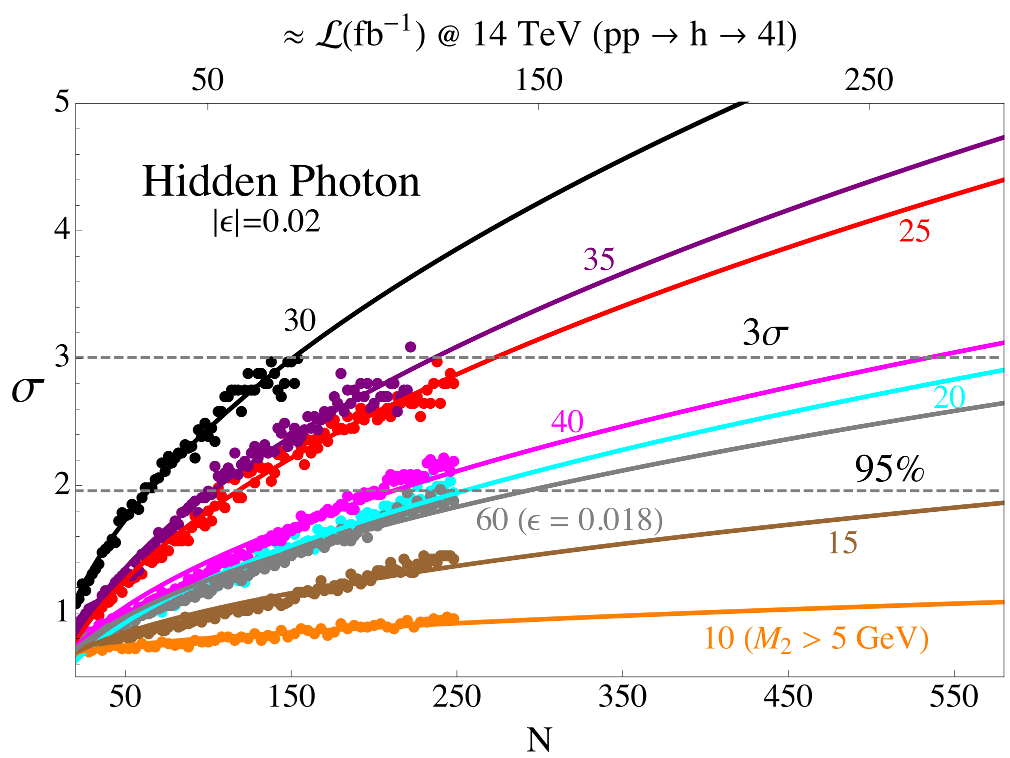
Larger branching fractions for $h \to ZX$ now allowed

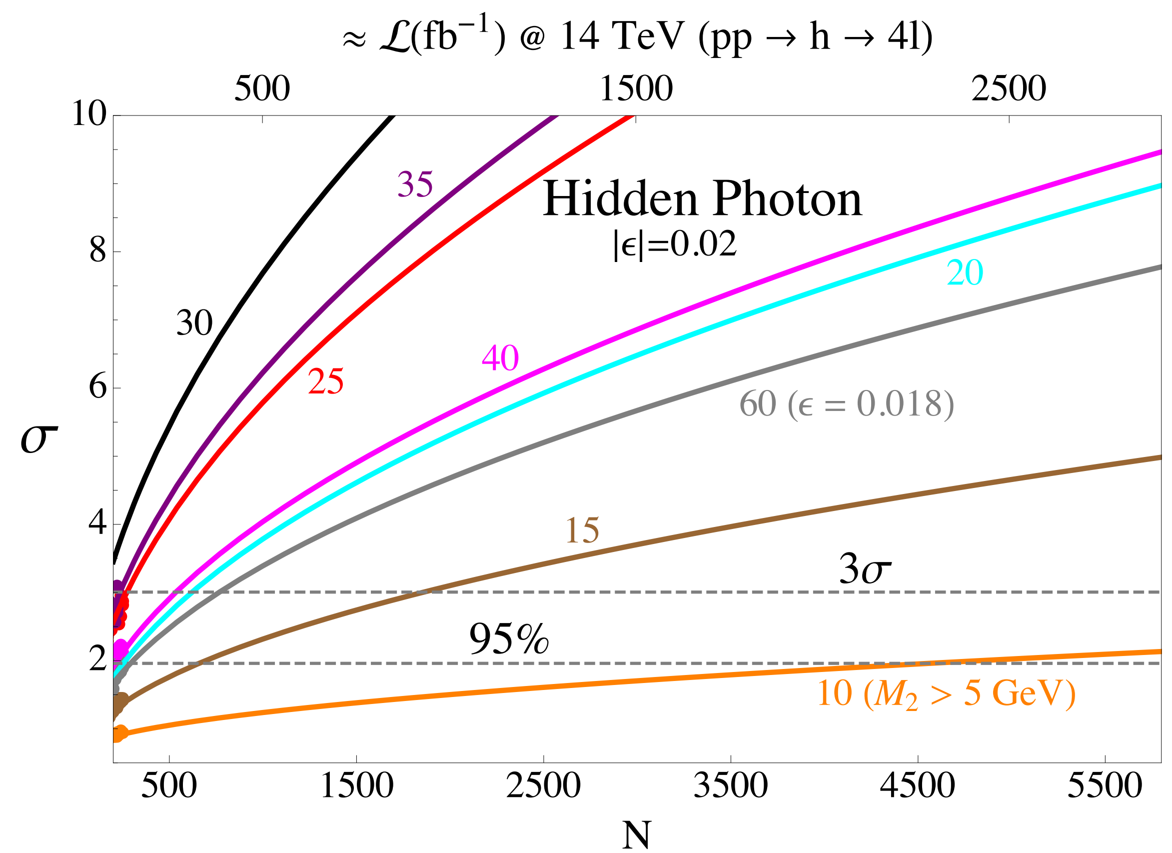


$$\Delta\mathcal{L}_{hXZ} = -\tan\theta_W X_{\mu\nu}\left(\epsilon_2 Z_{\mu\nu} + \epsilon_3\tilde{Z}_{\mu\nu}\right)$$

$$\Delta\mathcal{L}_{hX\gamma} = X_{\mu\nu}\left(\epsilon_2 A_{\mu\nu} + \epsilon_3\tilde{A}_{\mu\nu}\right)$$

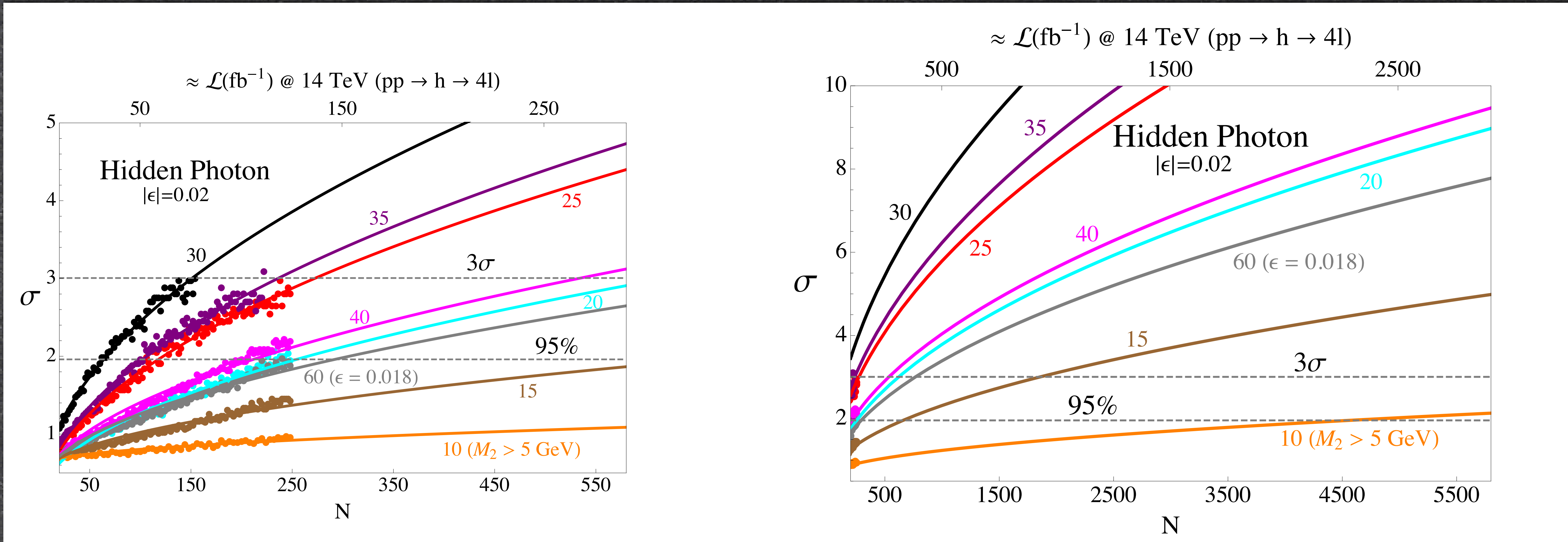
Hidden photon in the golden channel





m_X	ϵ	ϵ_2	ϵ_3	R
10	0.02	0	0	1.004
15	0.02	0	0	1.006
20	0.02	0	0	1.019
25	0.02	0	0	1.031
30	0.02	0	0	1.039
30	0.02	0.01	0	1.33
30	0.02	0	0.015	1.20
35	0.02	0	0	1.019
40	0.02	0	0	1.019
50	0.02	0	0	1.016
60	0.018	0	0	1.014

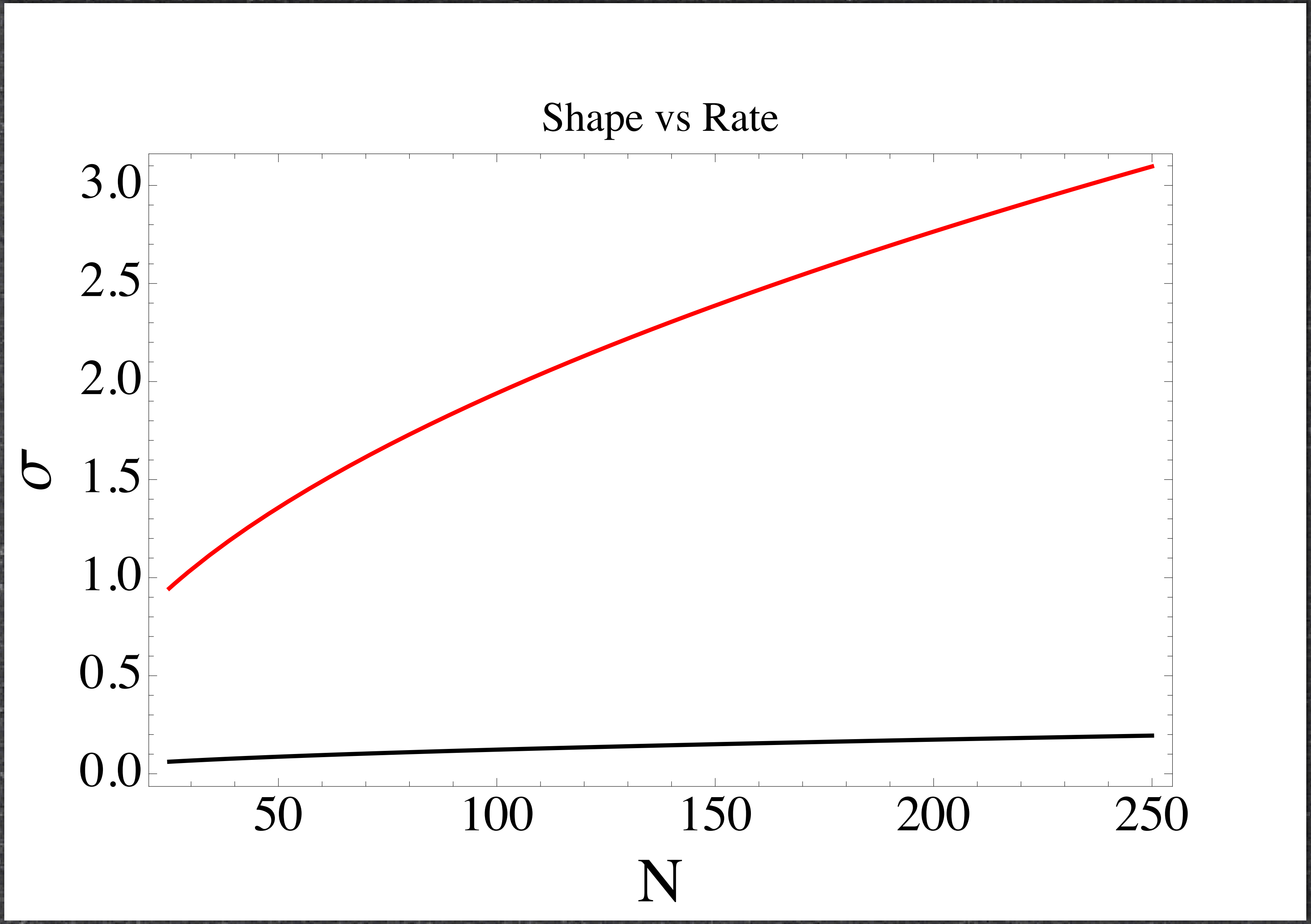
Hidden photon in the golden channel



- For mX close to 15-65 GeV vanilla model probed in LHC run-2
- Exclusion reach down to 10 GeV in high-luminosity LHC

Hidden photon in the golden channel

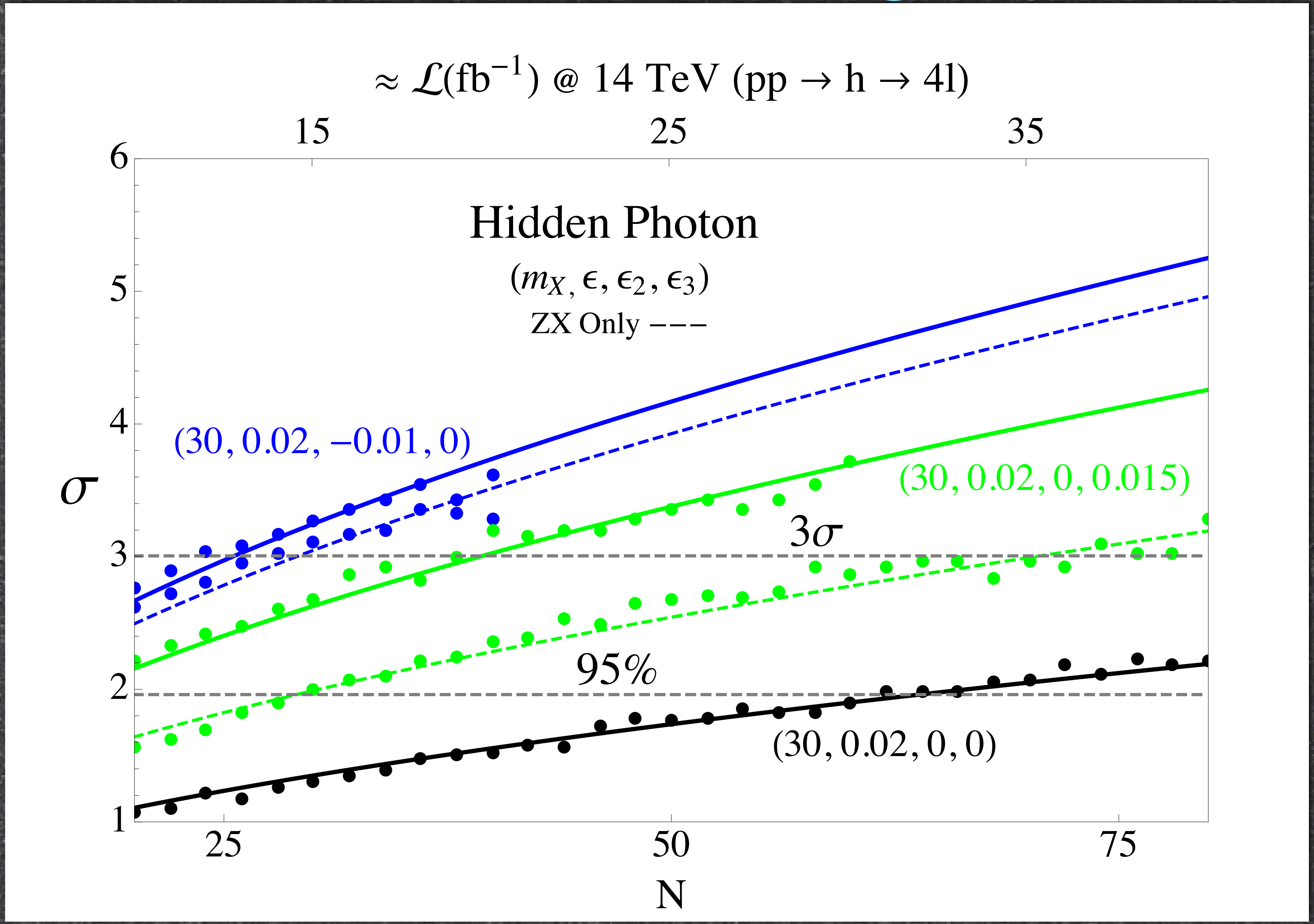
Practically all discrimination power from shape analysis



ε=0.02

m_X=30 GeV

Hidden photon in the golden channel

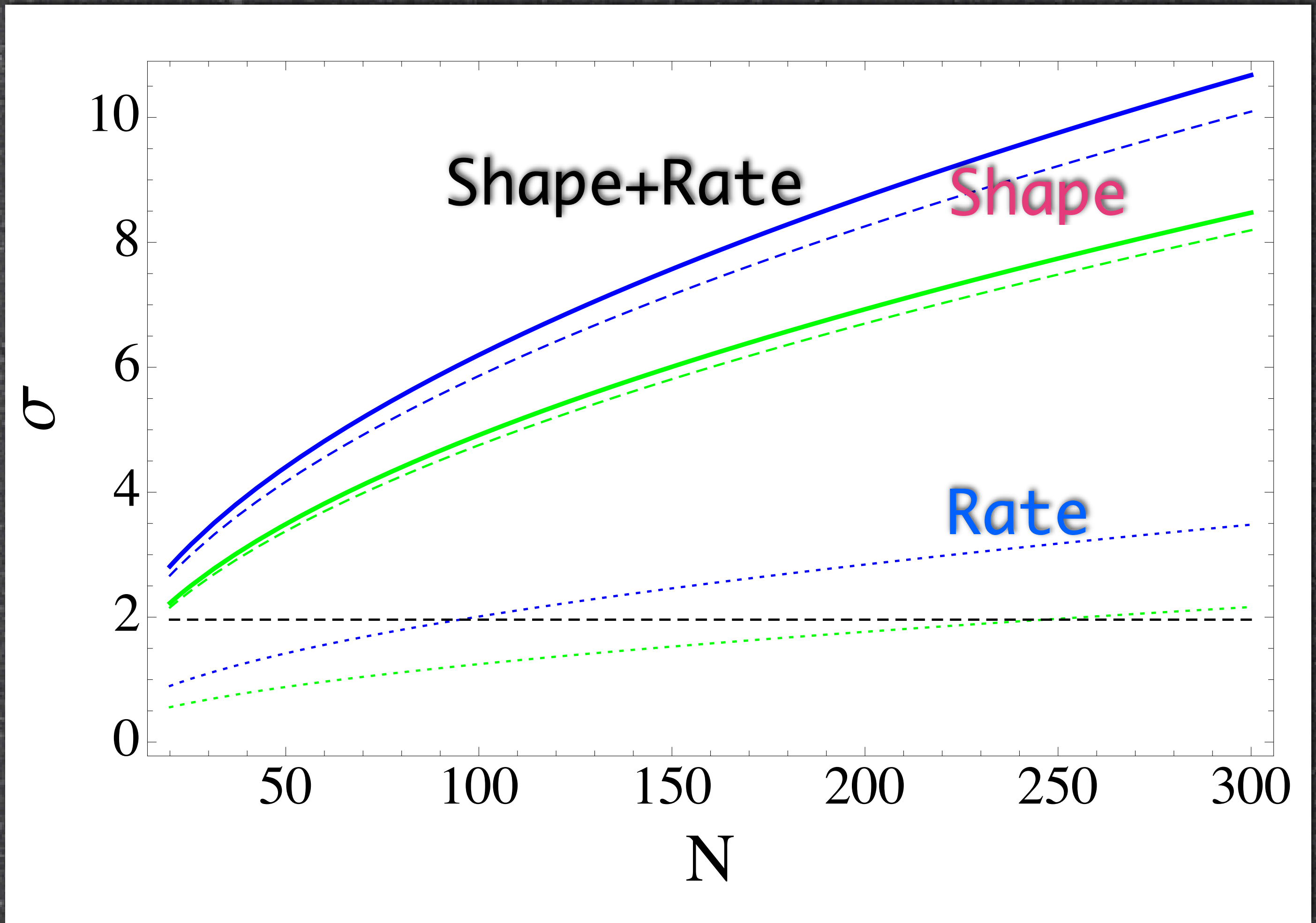


- Modified hidden photon model already being probed

$$\Delta\mathcal{L} = \frac{\epsilon_2}{\cos\theta_W}\left(\frac{|H|^2}{v^2} - \frac{1}{2}\right) B_{\mu\nu}\hat{X}_{\mu\nu} + \frac{\epsilon_3}{\cos\theta_W}\frac{|H|^2}{v^2}\tilde{B}_{\mu\nu}\hat{X}_{\mu\nu},$$

Hidden photon in the golden channel

Still better discrimination power from shape than rate



m_X	ϵ	ϵ_2	ϵ_3	R
10	0.02	0	0	1.004
15	0.02	0	0	1.006
20	0.02	0	0	1.019
25	0.02	0	0	1.031
30	0.02	0	0	1.039
30	0.02	0.01	0	1.33
30	0.02	0	0.015	1.20
35	0.02	0	0	1.019
40	0.02	0	0	1.019
50	0.02	0	0	1.016
60	0.018	0	0	1.014

Vector-like Lepton
in the golden channel

Vector-like lepton model

Vector-like lepton E interacting with SM lepton l via Yukawas

$$\mathcal{L} = -y\bar{\ell}_R H^\dagger l_L - M_E \bar{E}_R E_L - Y\bar{E}_R H^\dagger l + \text{h.c.}$$

After EW breaking vector-like and SM leptons mix

$$\begin{aligned} \ell_L &\to \cos\alpha_L \ell_L + \sin\alpha_L E_L, & E_L &\to -\sin\alpha_L \ell_L + \cos\alpha_L E_L, \\ \ell_R &\to \cos\alpha_R \ell_R + \sin\alpha_R E_R, & E_R &\to -\sin\alpha_R \ell_R + \cos\alpha_R E_R, \end{aligned} \quad \alpha_L = \frac{Yv}{\sqrt{2}M_E}\left(1 + \mathcal{O}(v^2/M_E^2)\right), \qquad \alpha_R = \mathcal{O}(v^2/M_E^2).$$

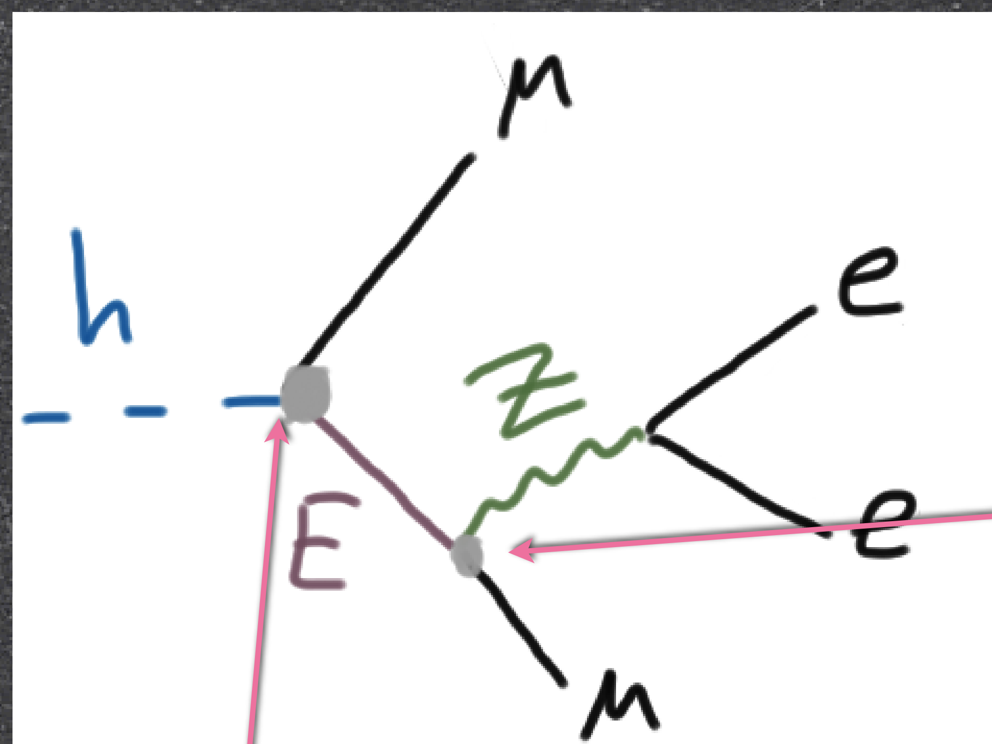
One consequence: couplings to Higgs

$$\mathcal{L} = -\frac{Y}{\sqrt{2}} h \bar{E}_R \ell_L + \text{h.c.}.$$

Another consequence: couplings to W and Z boson

$$\mathcal{L} = \frac{g_L}{\sqrt{2}} \alpha_L W_\mu^+ \bar{\nu}_L \gamma_\mu E_L - \frac{\sqrt{g_L^2 + g_Y^2}}{2} \alpha_L Z_\mu \bar{\ell}_L \gamma_\mu E_L$$

Vector-like lepton in the golden channel



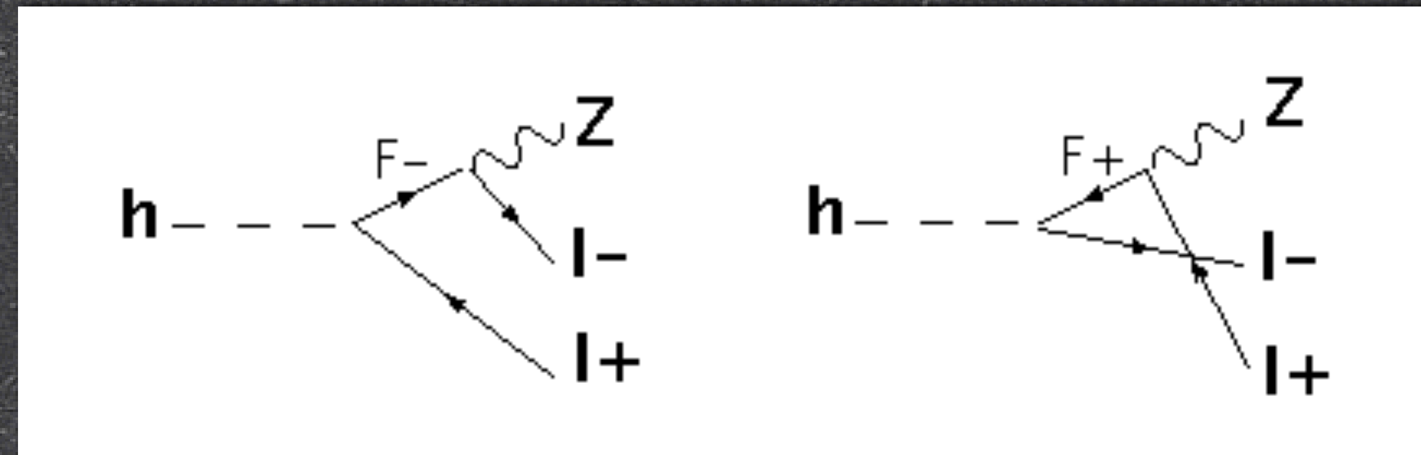
$$-\frac{\sqrt{g_L^2+g_Y^2}}{2}\alpha_L Z_\mu \bar{\ell}_L \gamma_\mu E_L$$

$$\mathcal{L} = -\frac{Y}{\sqrt{2}} h \bar{E}_R \ell_L + \text{h.c.}.$$

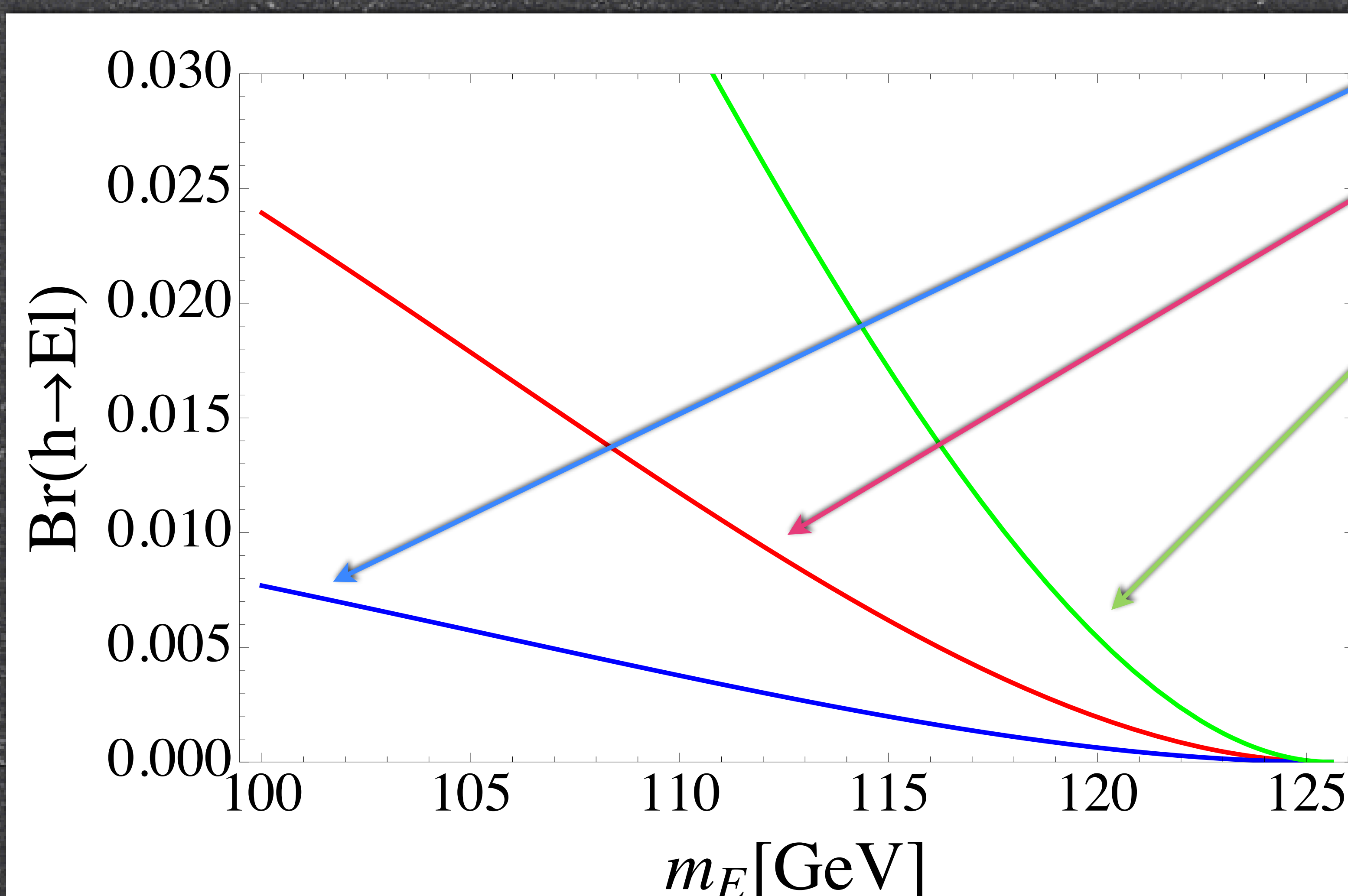
Vector-like lepton in the golden channel

Higgs decay channel:

$h \to l\,E \to Zll \to 4l$



Limits on branching fraction:



EW precision tests:

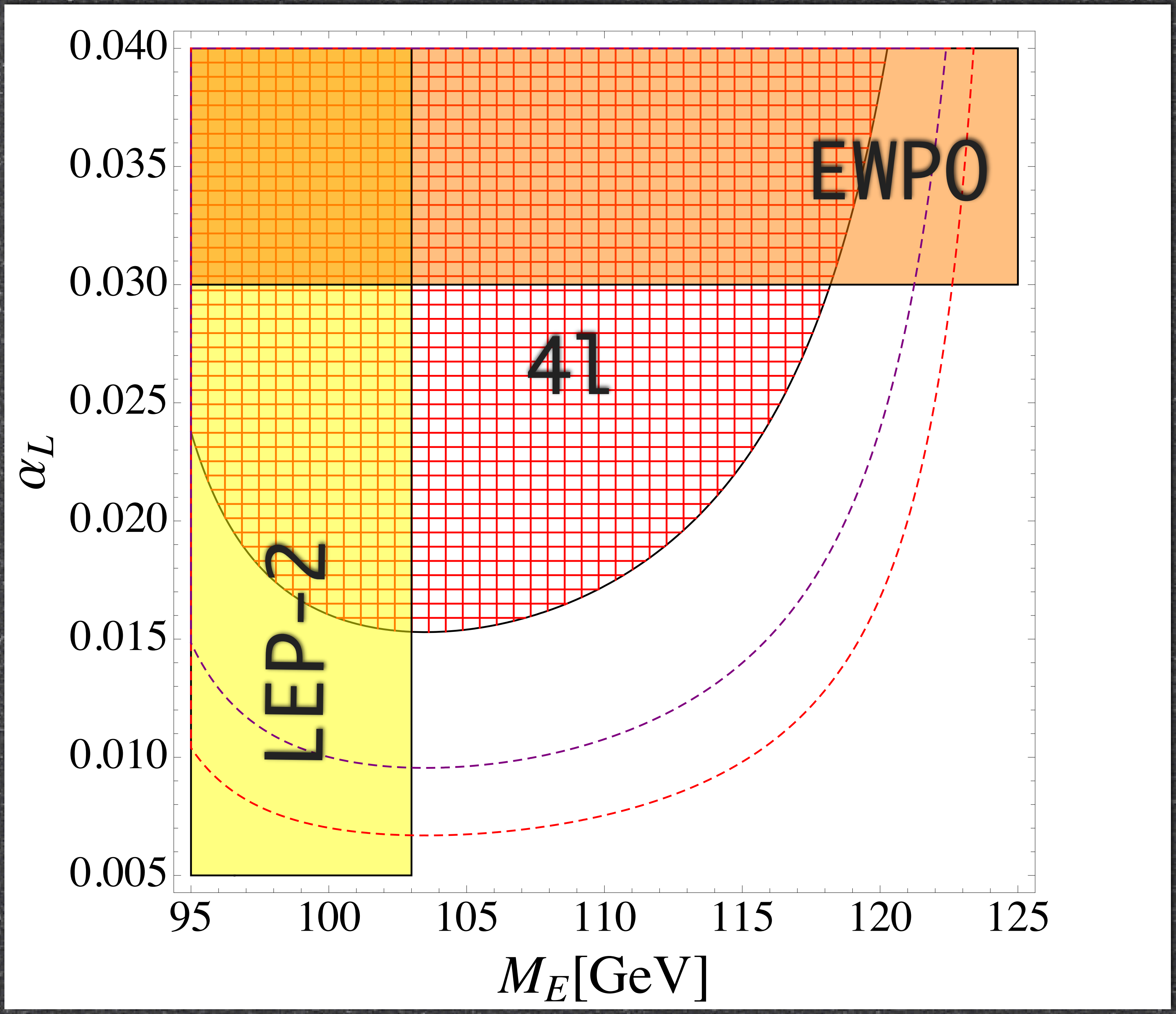
$$(e) \qquad \alpha_L < 0.017,$$
$$(\mu) \qquad \alpha_L < 0.030,$$
$$(\tau) \qquad \alpha_L < 0.050.$$

Plus direct LEP limit

ME > 103 GeV

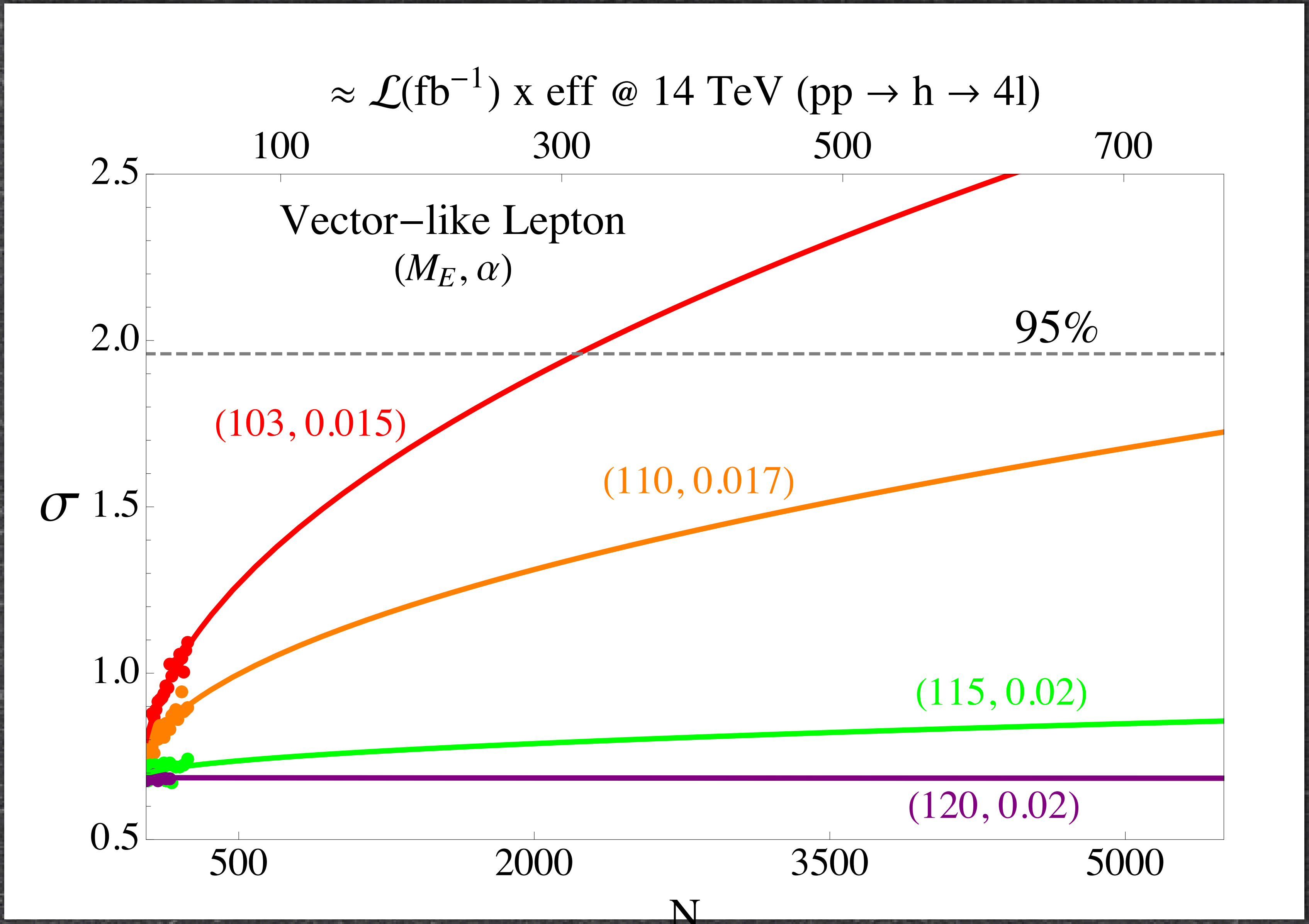
Vector-like lepton in the golden channel

Parameter Space



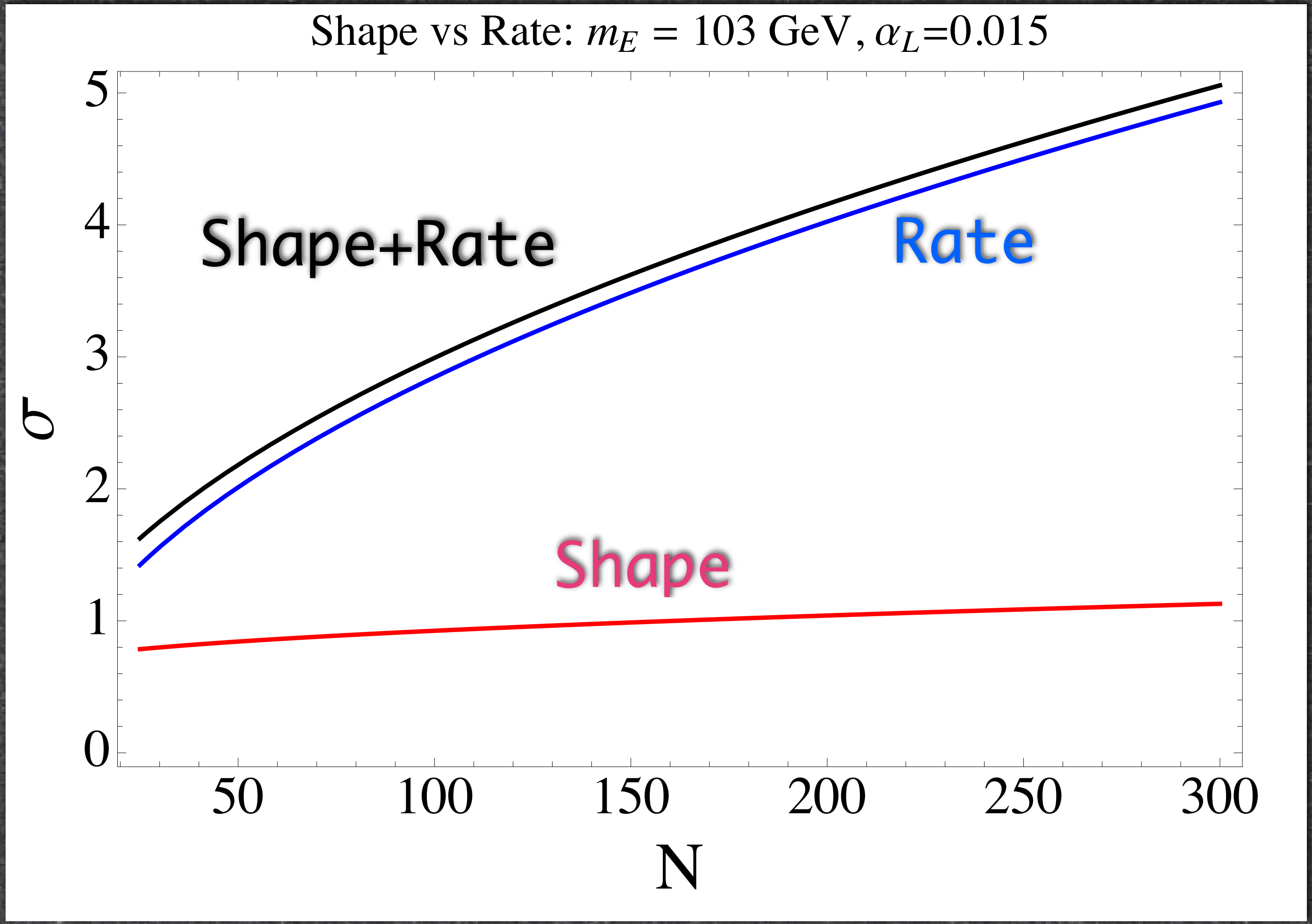
Vector-like lepton in the golden channel

Discrimination using shape only



Hidden photon in the golden channel

Comparable discrimination power from shape and rate analyses



- For this model, shape variables are less powerful than simple event counting

M_E	(α)	Ratio (No Cuts)	Ratio (CMS)	$\sigma(N)$ fit
103	0.015	1.45	1.48	$0.646 + 0.0279\sqrt{N}$
103	0.017	1.57	1.70	$0.679 + 0.0199\sqrt{N}$
110	0.017	1.42	1.57	$0.684 + 0.0140\sqrt{N}$
115	0.02	1.34	1.08	$0.685 + 0.00231\sqrt{N}$
120	0.02	1.26	0.95	$0.686 - 0.0000241\sqrt{N}$

Table 4: Table of 'vector-like lepton' results.

Summary

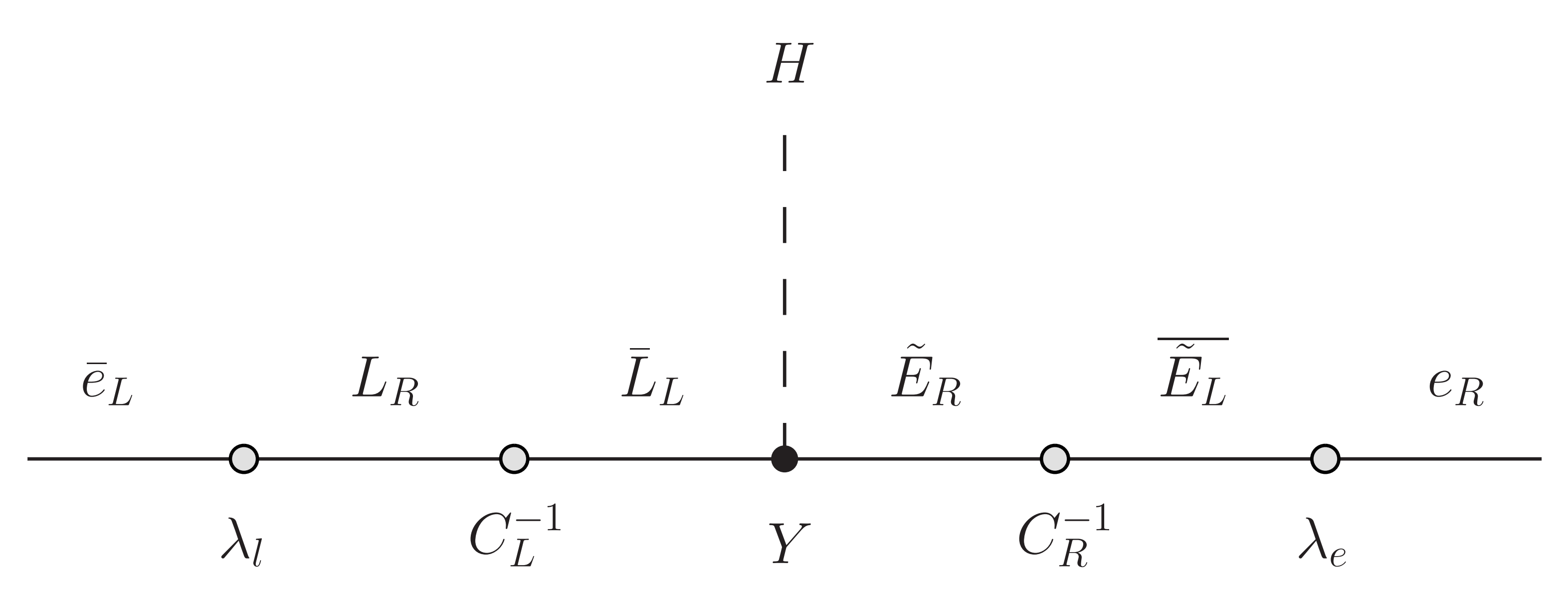
- Exotic Higgs decays may be the portal to new physics
- Large exotic decay rates readily possible if there exists a light BSM degree of freedom coupled to Higgs
- Exotic decays could show up in standard Higgs analyses, e.g. in the golden channel
- If no light degrees of freedom then stringent constrains within EFT, but a few window of opportunities remain

Backup

Exotic Higgs Decays from composite Higgs

LFV decays from composite leptons

- Partial compositeness: SM leptons mix with heavy vector-like leptons
- Flavor violation in composite sector feeds through this mixing to SM

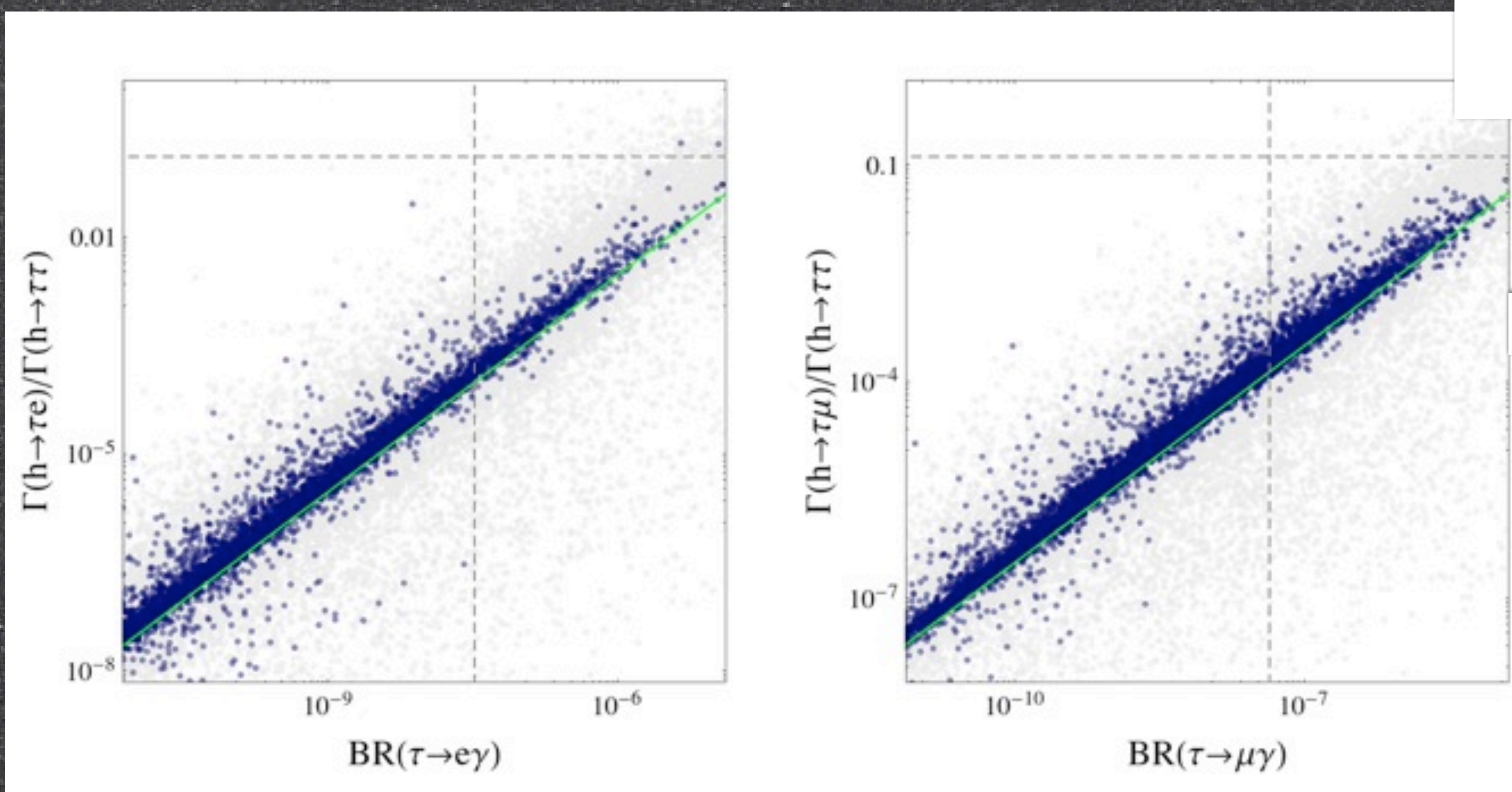


LFV decays from composite leptons

- But generically correlation between Higgs LFV decays and radiative LFV lepton decays

$$\frac{\mathrm{BR}(h \to e_i e_j)}{\mathrm{BR}(e_i \to e_j \gamma)} = \frac{\mathrm{BR}(h \to e_i e_i)_{\mathrm{SM}}}{\mathrm{BR}(e_i \to e_j \nu_i \bar{\nu}_j)} \frac{4\pi}{3\alpha}$$

$$\mathrm{BR}(h \to \tau\mu) < 8.6 \times 10^{-6} \left[\frac{\mathrm{BR}(\tau \to \mu\gamma)}{4.4 \times 10^{-8}}\right],$$
$$\mathrm{BR}(h \to \tau e) < 6.2 \times 10^{-6} \left[\frac{\mathrm{BR}(\tau \to e\gamma)}{3.3 \times 10^{-8}}\right],$$
$$\mathrm{BR}(h \to \mu e) < 6.7 \times 10^{-14} \left[\frac{\mathrm{BR}(\mu \to e\gamma)}{5.7 \times 10^{-13}}\right],$$



No observables LFV Higgs decays from composite leptons is possible