Status of the SMEFT at LHC and some cosmological implications.

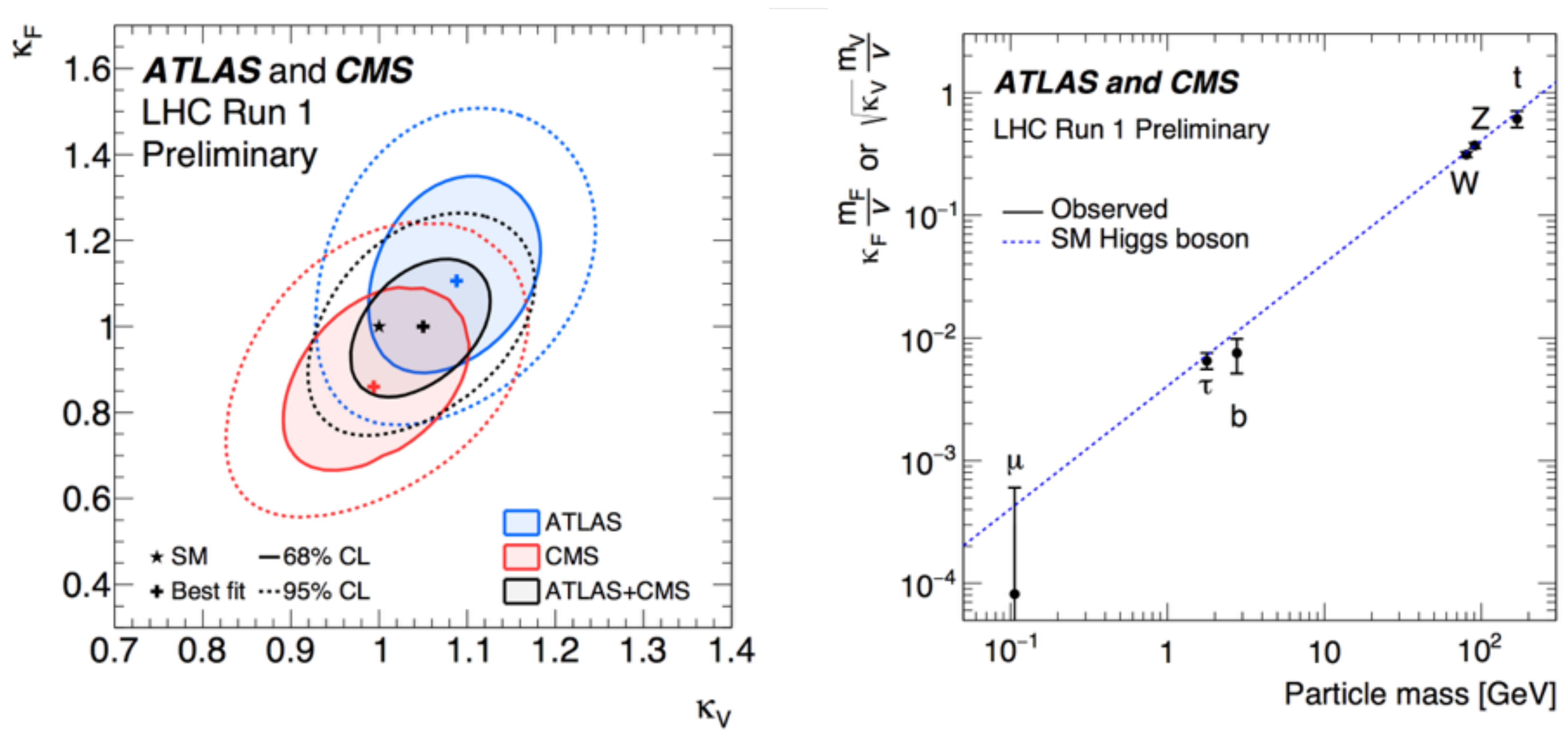
Michael Trott

Moriond 2016

Affiliations: NBIA & Discovery Center, Copenhagen University.

Run I Legacy

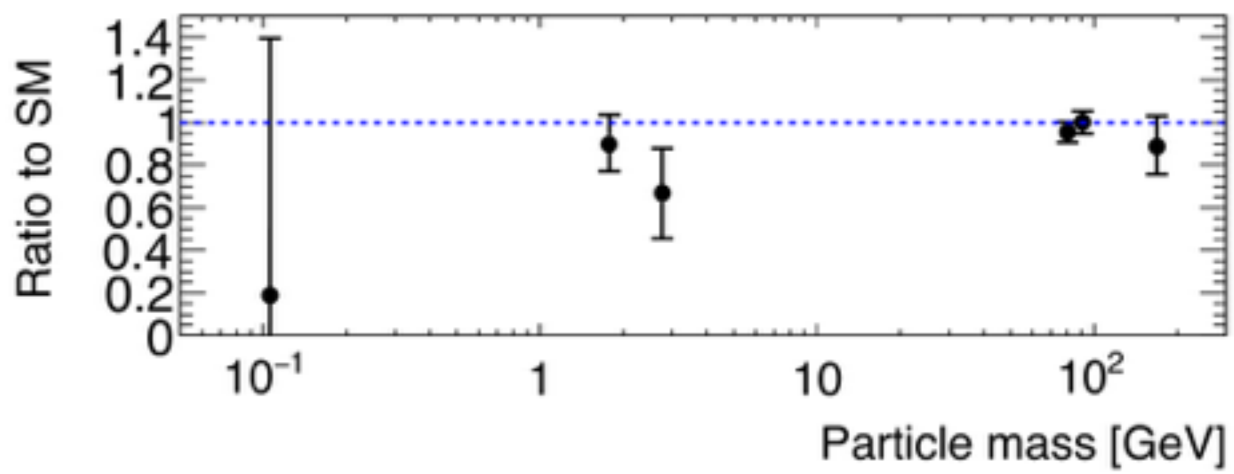
- What do we know? Without a doubt a very Higgs like boson.

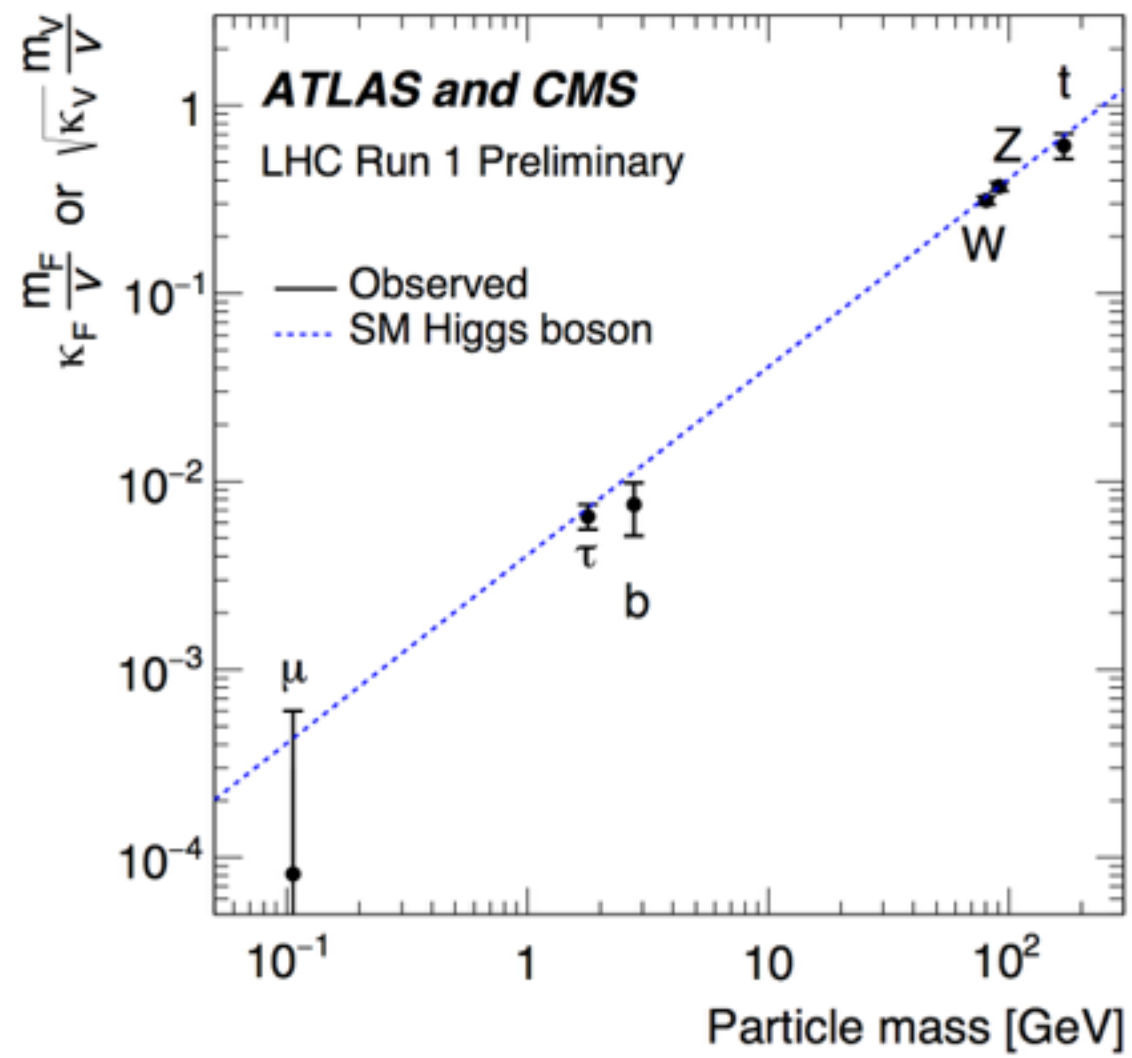


The Cut Off scale(s)

- What do we know? Without a doubt a very Higgs like boson.

However… recall.. didn't Feynman have something to say about log-log plots?





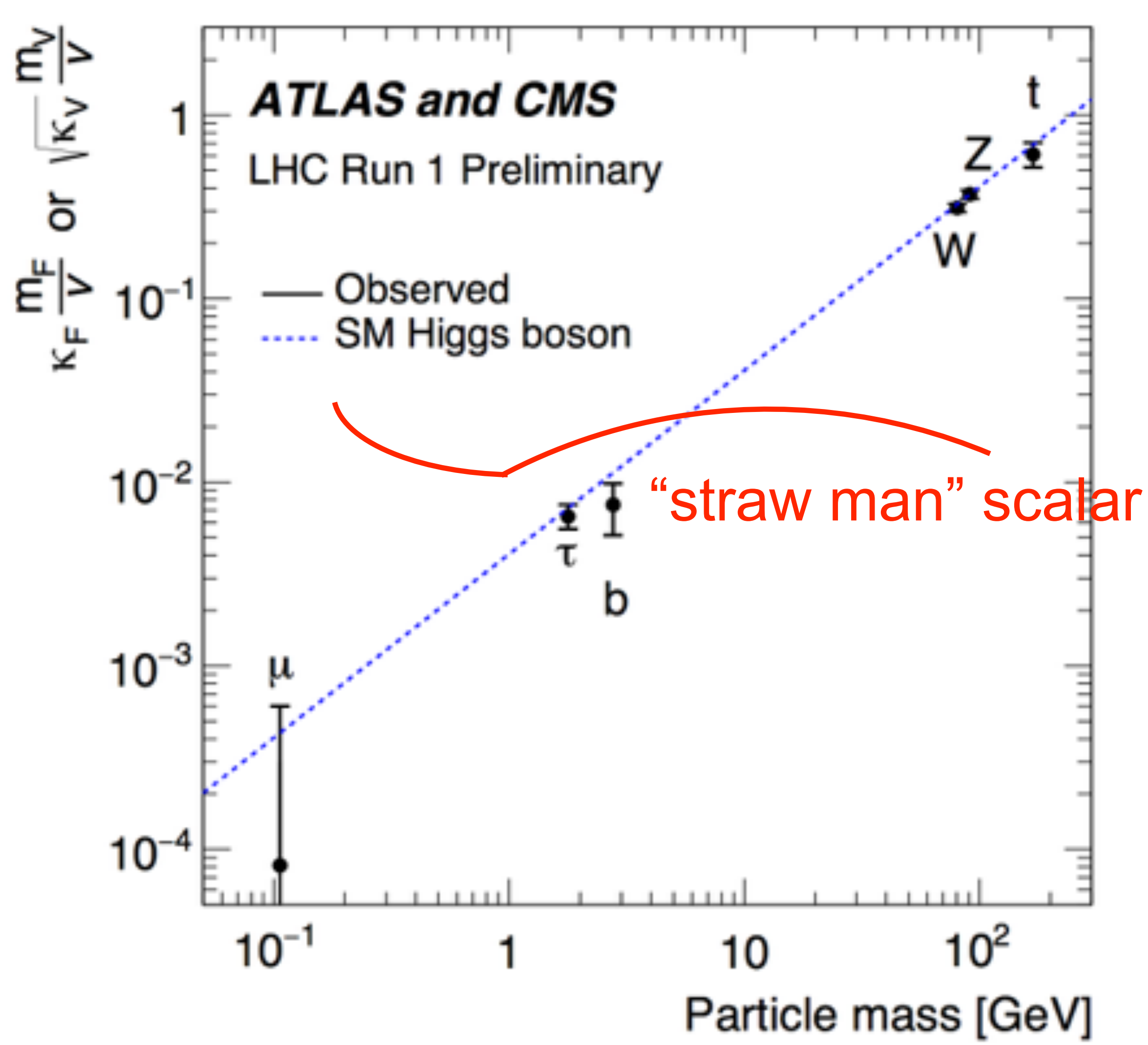
Thats a bit better..

The Cut Off scale(s)

- What do we know? Without a doubt a very Higgs like boson.

1. SM is of course consistent with the data.

2. Scalar that has nothing to do with EWSB is not interesting as an “imposter” now.



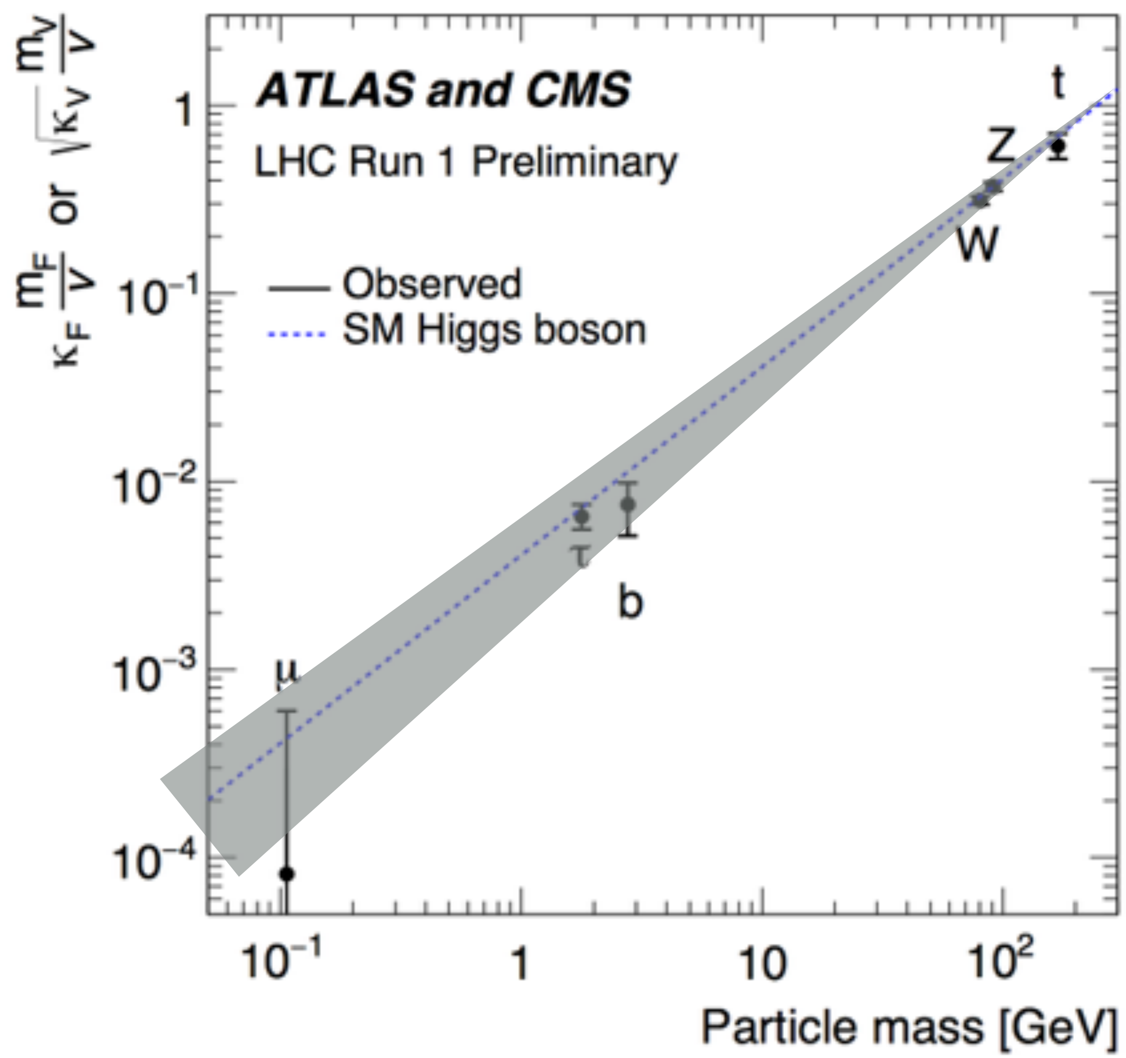
The Cut Off scale(s)

- What do we know? Without a doubt a very Higgs like boson.

1. SM is of course consistent with the data.

3. Relevant scalars, and SMEFT deformations (linear and nonlinear) that are involved with separating the cut off scale from the scale "v" - different story.

Reason: The SM dependence is not random. The mission of the Higgs is to "solve" the unitarity problem of the Higgsless SM.



The Cut Off scale(s)

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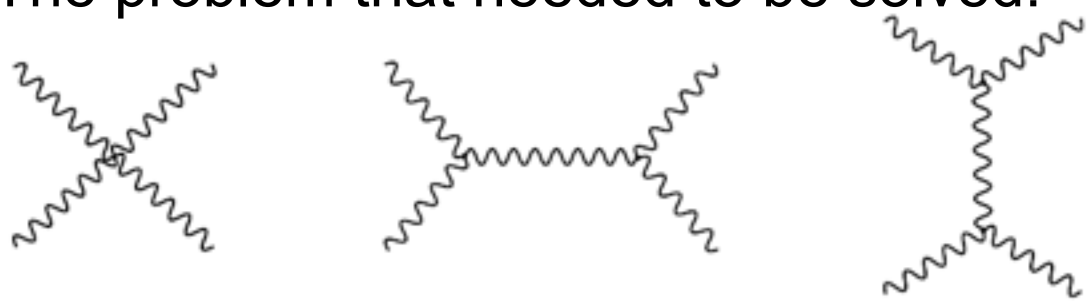
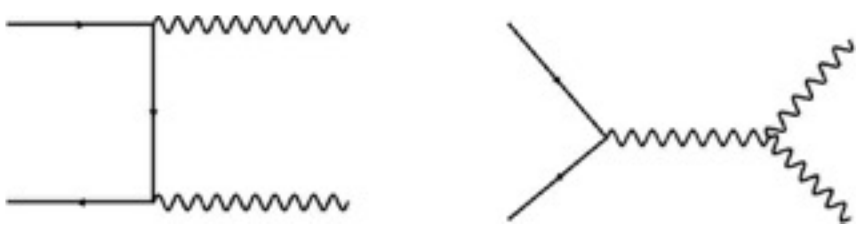
The problem that needed to be solved:

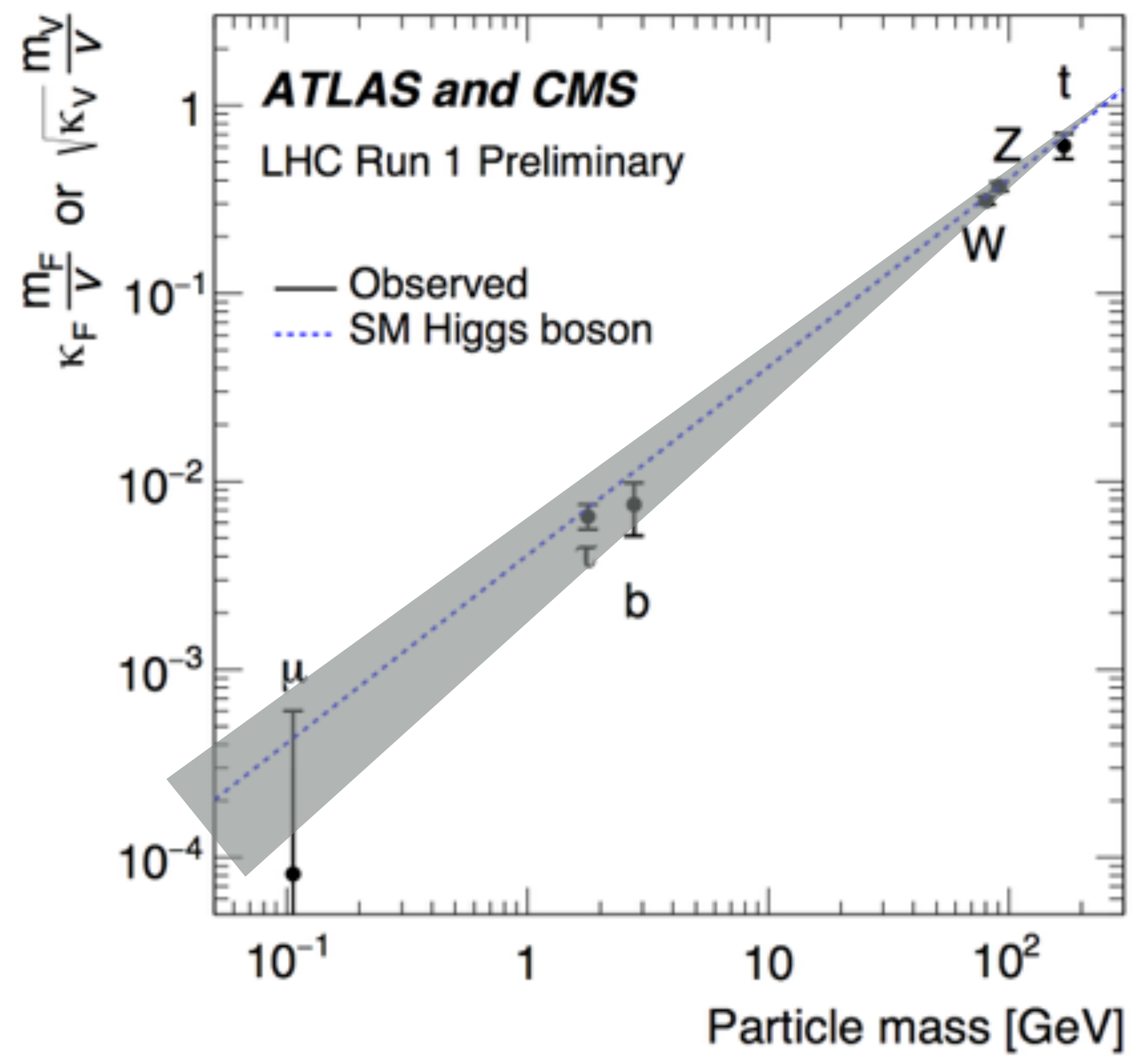


$$W_L^+ W_L^- \to W_L^+ W_L^- \;:\quad \mathcal{A} \simeq \frac{g^2}{4\, m_W^2}\,(s+t)$$

$$\epsilon_L^\mu \simeq p^\mu / m_W$$



$$\psi\,\bar{\psi} \to W_L^+ W_L^- \;: \mathcal{A} \simeq \frac{m_\psi \sqrt{s}}{v^2}$$

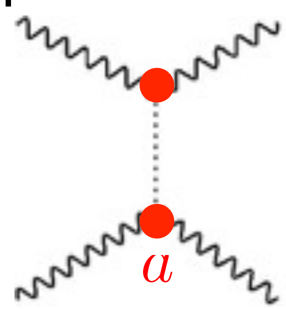


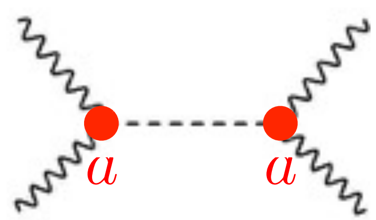
The Cut Off scale(s)

- What do we know? Without a doubt a very Higgs like boson.

<u>1. SM is of course consistent with the data.</u>

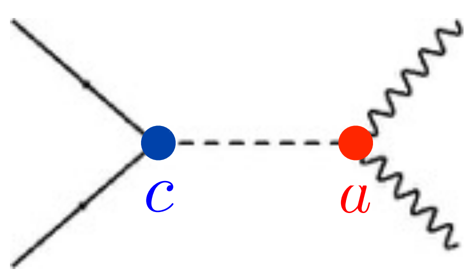
The problem that needed to be solved:



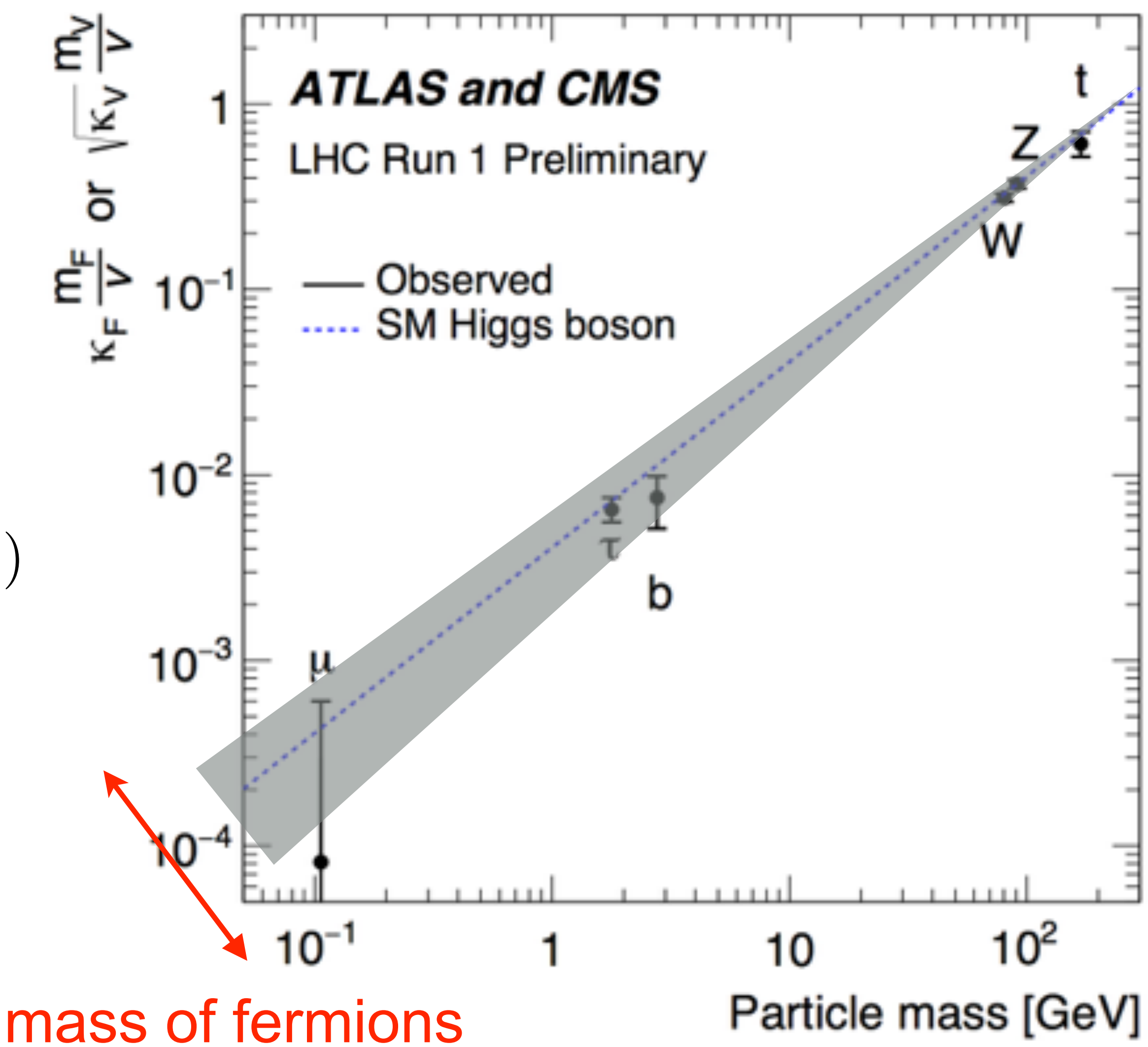


$$W_L^+ W_L^- \to W_L^+ W_L^- : \mathcal{A} \simeq \frac{g^2}{4\, m_W^2} (s+t)\,(1-a^2)$$

$$\epsilon_L^\mu \simeq p^\mu / m_W$$



$$\psi\, \bar{\psi} \to W_L^+ W_L^- : \quad \mathcal{A} \simeq \frac{m_\psi \sqrt{s}}{v^2}\,(1 - a\, c)$$



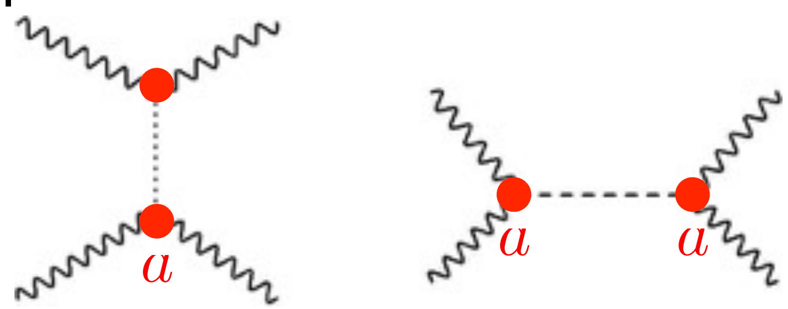
Lighter mass of fermions suppress unitarity violation to larger scales if couplings deviate from SM.

The Cut Off scale(s)

- What do we know? Without a doubt a very Higgs like boson.

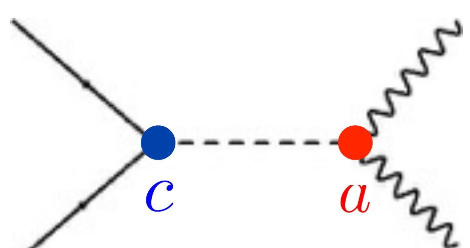
1. SM is of course consistent with the data.

The problem that needed to be solved:



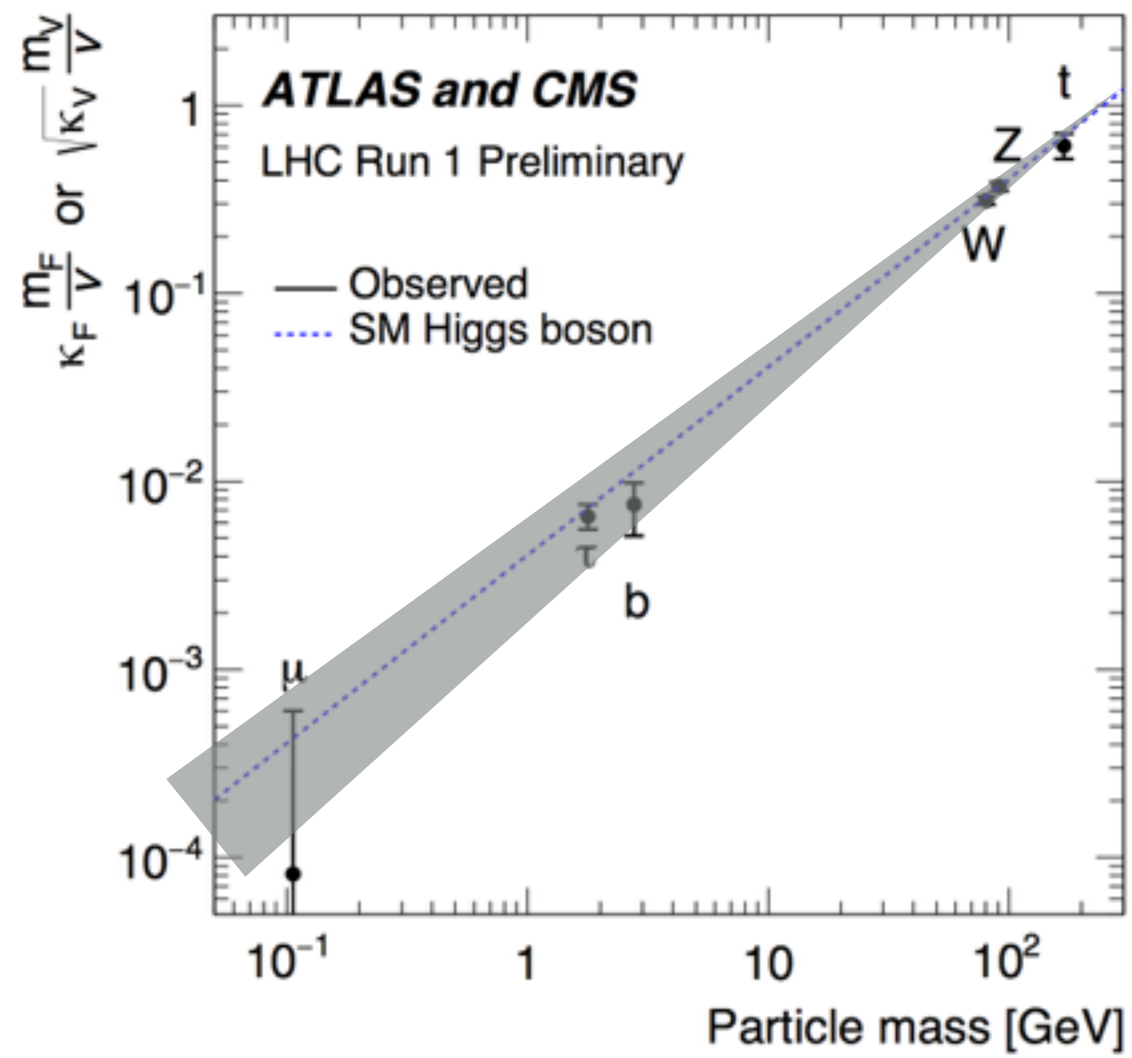
$$W_L^+ W_L^- \to W_L^+ W_L^- : \mathcal{A} \simeq \frac{g^2}{4\, m_W^2}\,(s+t)\,(1-a^2) \to 0$$

$$\epsilon_L^\mu \simeq p^\mu / m_W$$



Perfect solution to this problem is the SM Higgs.

$$\psi\,\bar{\psi} \to W_L^+ W_L^- : \quad \mathcal{A} \simeq \frac{m_\psi \sqrt{s}}{v^2}\,(1-a\,c) \to 0$$



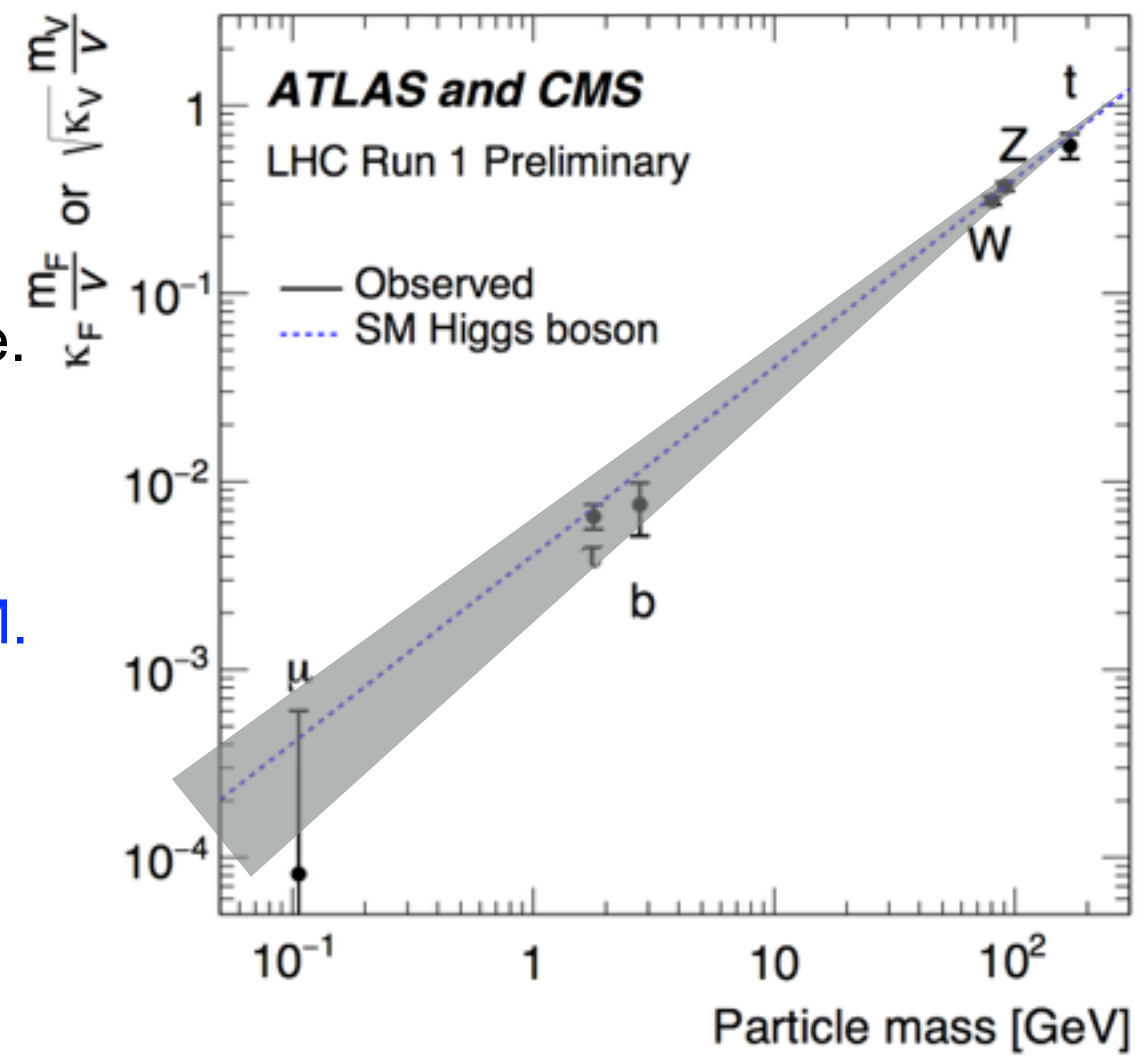
"Higgs like boson" is not a silly statement.
It has to look roughly like this as it is not raining NP particles near the EW scale.

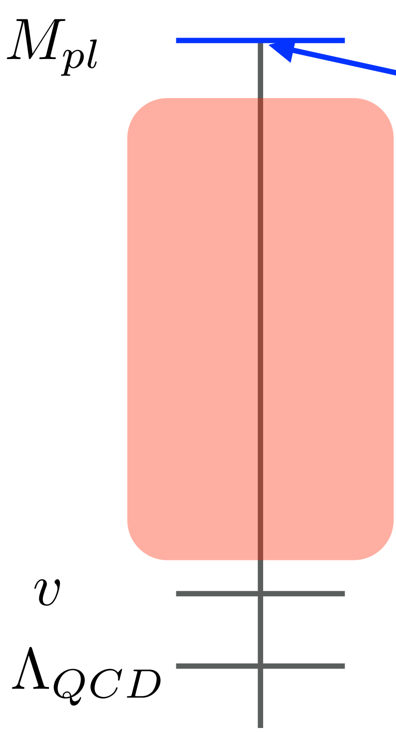
The Cut Off scale(s)

- What do we know? Without a doubt a very Higgs like boson.

1. SM is of course consistent with the data.

Lesson: The observed Higgs like boson pushed the cut off scale away from the EW scale.





Exactly the SM Higgs.
Nothing else coupled to the SM.

"Higgs like scalar" cut off scales

Relevant question is - how far is the cut off scale?

There is a cut off scale.

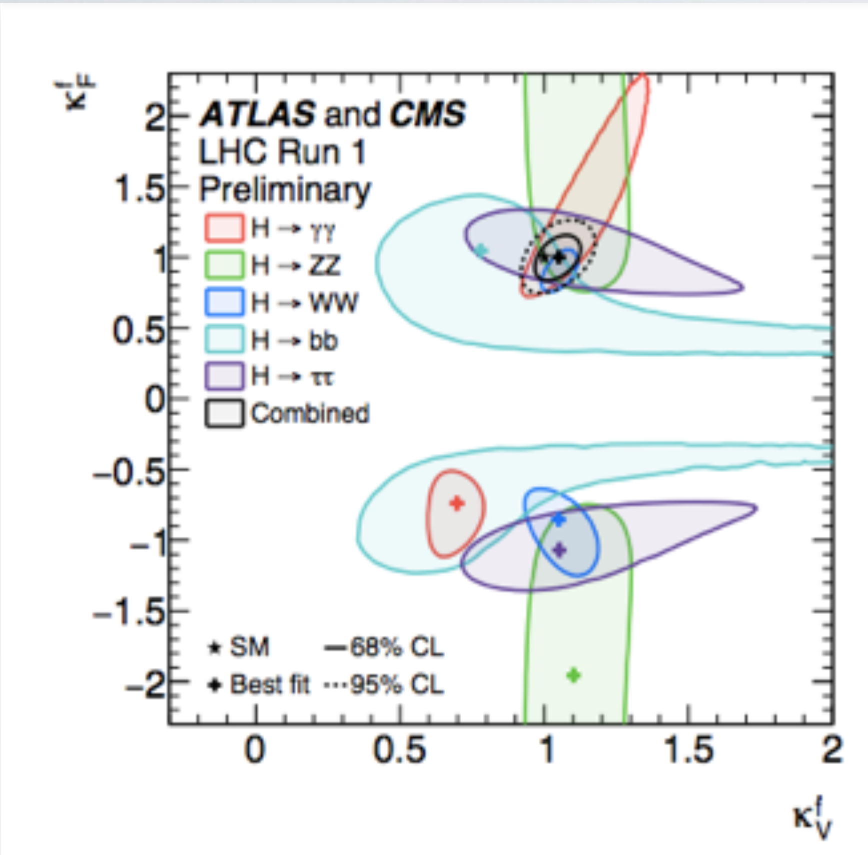
- Where is dark matter in the SM?
- Where is inflation in the SM?

  re (minimal) Higgs inflation - end of talk.
- Minimal baryogenesis in the SM is out.

  Leptogenesis at a high scale might be right.
- What is the origin of neutrino mass? Beyond the dim 5 op.
- It is clear that the SM (if assumed) breaks down at some scale. Where are the corrections, where is everyone?

We are getting to the right sensitivity

- Recent Higgs data:

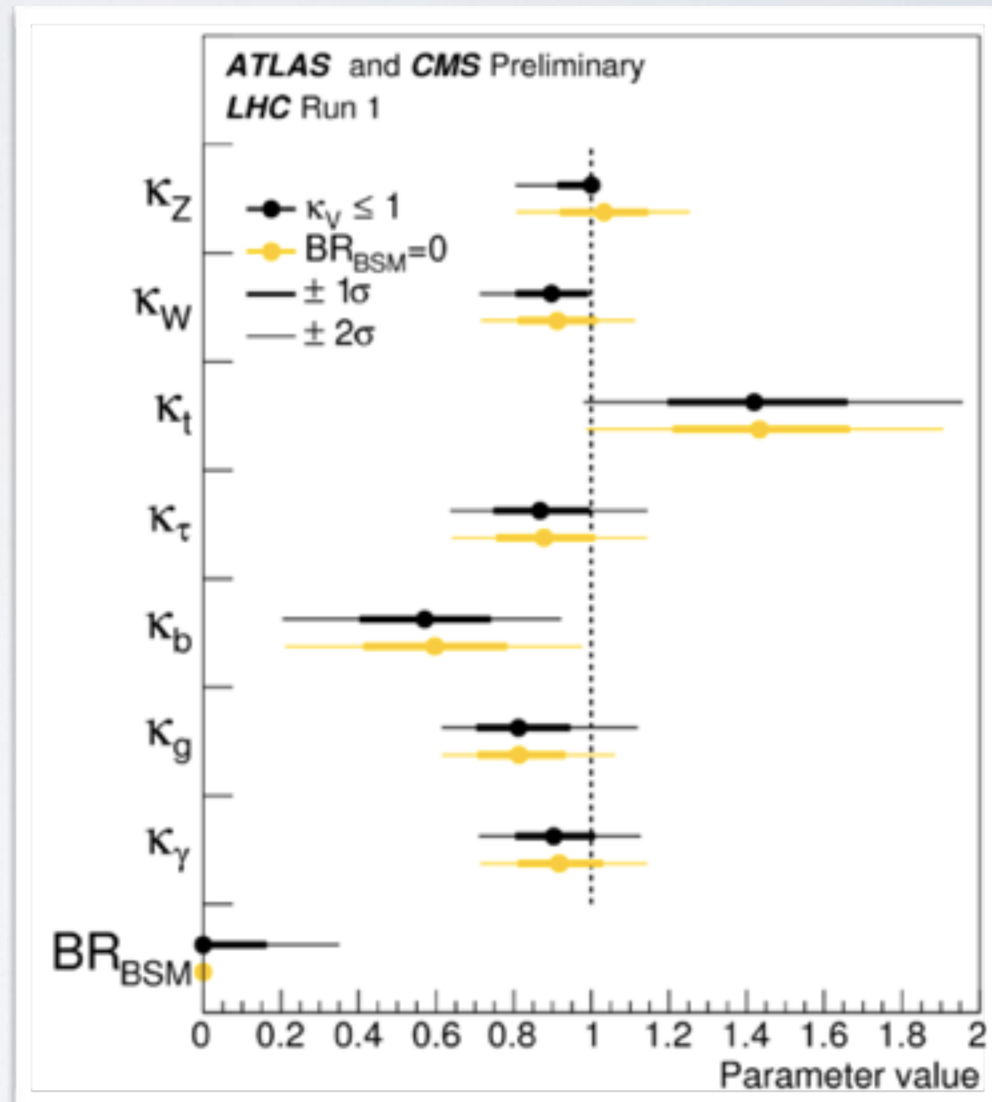


Facility	LHC	HL-LHC	TLEP (4 IPs)
$\sqrt{s}$ (GeV)	14,000	14,000	240/350
$\int \mathcal{L}dt$ (fb^{-1})	300/expt	3000/expt	10,000+2600
κ_γ	$5-7\%$	$2-5\%$	1.45%
κ_g	$6-8\%$	$3-5\%$	0.79%
κ_W	$4-6\%$	$2-5\%$	0.10%
κ_Z	$4-6\%$	$2-4\%$	0.05%
κ_ℓ	$6-8\%$	$2-5\%$	0.51%
$\kappa_d = \kappa_b$	$10-13\%$	$4-7\%$	0.39%
$\kappa_u = \kappa_t$	$14-15\%$	$7-10\%$	0.69%

- Pushing LHC to be as precise as possible in predictions and measurements essential to reach expected deviations. This is just barely the machine we need.

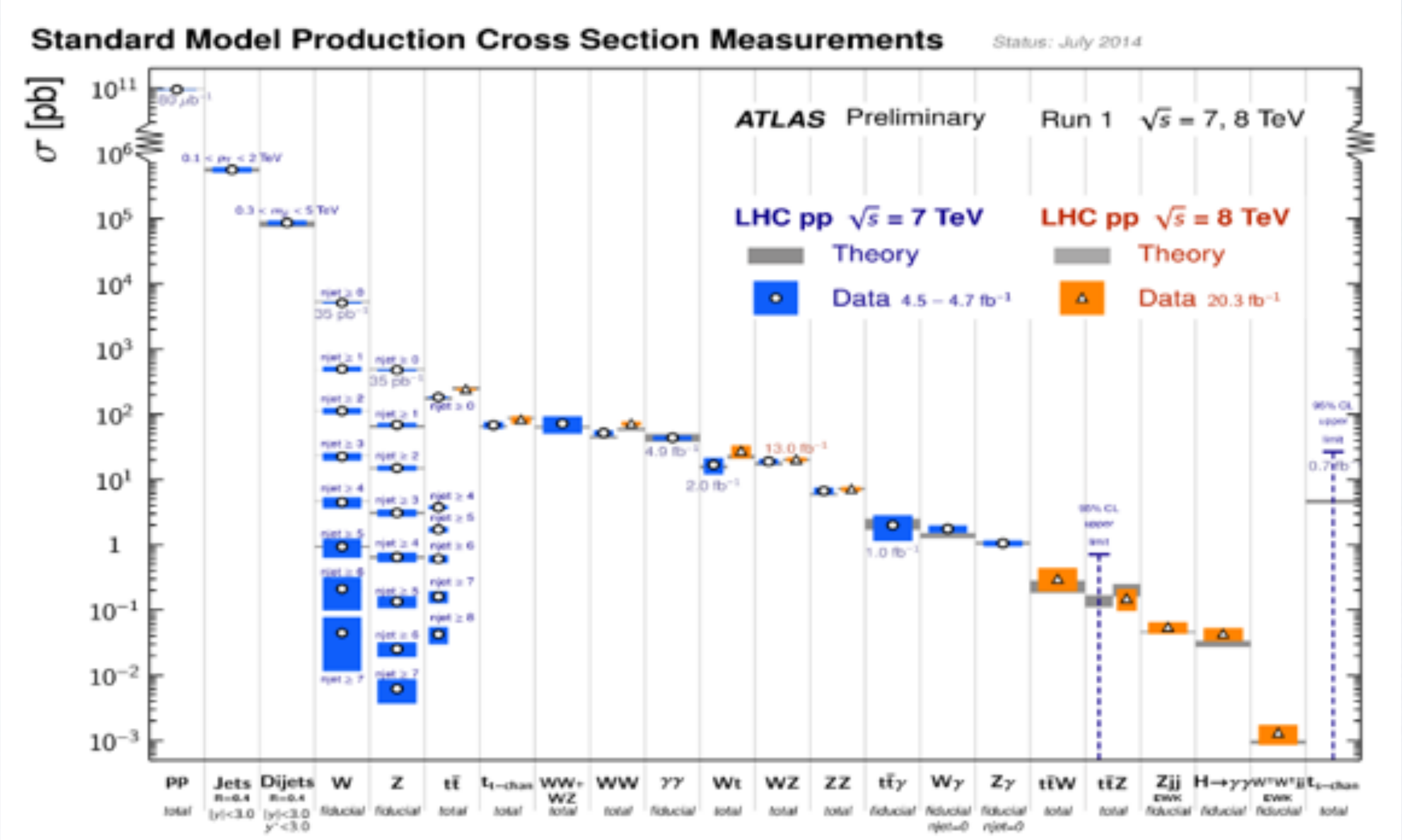
- We are just NOW getting into the interesting region for Higgs measurements.

$$\frac{v^2}{\Lambda^2} \sim few\,\%$$



Current state of affairs:

- Deviations “naturally” expected not robustly ruled out, but very hopefull scenarios - $m_{new} \sim v$ - not looking good.



- plan going forward:

> **...we just calmly laid out all the options, and failure was not one of them.**
>
> *Jerry C. Bostick*
> *Flight Dynamics Officer (FDO) Apollo 13*

Going bottom up..

What is the EFT: 1)Nonlinear EFT

Two options. Not obvious to choose between them for cut off scale reasons stated.

1) Nonlinear EFT - built of

Idea stumbled upon over and over..
F. Feruglio arXiv:hepph/9301281
Burgess et al. 9912459
Grinstein Trott , arXiv:0704.1505

$$\Sigma = e^{i\sigma_a \pi^a/v} \quad h$$

$$\mathcal{L} = -\frac{1}{4}W^{\mu\nu}W_{\mu\nu} - \frac{1}{4}B^{\mu\nu}B_{\mu\nu} - \frac{1}{4}G^{\mu\nu}G_{\mu\nu} + \bar{\psi}iD\psi$$

$$+ \frac{v^2}{4}\mathrm{Tr}(D_\mu\Sigma^\dagger D^\mu\Sigma) - \frac{v}{\sqrt{2}}(\bar{u}^i_L \bar{d}^i_L)\,\Sigma \begin{pmatrix} y^u_{ij}\, u^j_R \\ y^d_{ij}\, d^j_R \end{pmatrix} + h.c.,$$

"Higgs like boson" couplings are given by adding all possibly "h" interactions

$$\mathcal{L} = \frac{1}{2}(\partial_\mu h)^2 - V(h) + \frac{v^2}{4}\mathrm{Tr}(D_\mu\Sigma^\dagger D^\mu\Sigma)\left[1 + 2\,a_{W,Z}\,\frac{h}{v} + b_{Z,W}\,\frac{h^2}{v^2} + b_{3,Z,W}\,\frac{h^3}{v^3} + \cdots\right],$$

$$-\frac{v}{\sqrt{2}}(\bar{u}^i_L \bar{d}^i_L)\,\Sigma\left[1 + c^{u,d}_i\,\frac{h}{v} + c^{u,d}_{2,j}\,\frac{h^2}{v^2} + \cdots\right]\begin{pmatrix} y^u_{ij}\, u^j_R \\ y^d_{ij}\, d^j_R \end{pmatrix} + h.c.,$$

$$V(h) = \frac{1}{2}m_h^2\,h^2 + \frac{d_3}{6}\left(\frac{3\,m_h^2}{v}\right)h^3 + \frac{d_4}{24}\left(\frac{3m_h^2}{v^2}\right)h^4 + \cdots.$$

SM mass scales then unrelated to scalar couplings - ***this is used in the "kappa" fits.***

Nonlinear EFT: Rapid developments

- Used in Higgs data analysis and developed into kappa formalism

  1202.3415 Azatov, Contino galloway , 1202.3697 Espinosa, Grojean, Muhlleitner,, MT

  1209.0040 Higgs XS working group 1504.01707 Buchalla et al.

- Subleading operator basis developed

  1203.6510 Buchalla Cata, 1307.5017 Buchalla Cata Krause 1212.3305 Alonso et al.

- Matchings/correlations explored

  1311.1823 Brivio et al. 1405.5412 Brivio et al. 1406.6367 Gavela et al.
  1409.1589 Alonso et al. 1603.05668 Feruglio et al. 1412.6356 Buchalla et al.

- Power counting discussion

  1312.5624 Buchalla et al, 1601.07551 Gavela et al. 1603.03062 Buchalla et al.

- Curvature interpretation

  1511.00724 1602.00706 Alonso et al.

What is the EFT: 2)Linear SMEFT

Linear EFT - built of H doublet + higher D ops

$$\mathcal{L} = \mathcal{L}_{SM} + \frac{1}{\Lambda_{\delta L \neq 0}} \mathcal{L}_5 + \frac{1}{\Lambda^2_{\delta B = 0}} \mathcal{L}_6 + \frac{1}{\Lambda^2_{\delta B \neq 0}} \mathcal{L}'_6 + \frac{1}{\Lambda^3_{\delta L \neq 0}} \mathcal{L}_7 + \frac{1}{\Lambda^4} \mathcal{L}_8 + \cdots$$

Glashow 1961, Weinberg 1967 (Salam 1967)

Weinberg 1977

Leung, Love, Rao 1984, Buchmuller Wyler 1986,
Grzadkowski, Iskrzynski, Misiak,Rosiek 2010

Weinberg 1979, Abbott Wise 1980

Lehman 1410.4193, Henning et al. 1512.03433

Lehman,Martin 1510.00372, Henning et al. 1512.03433

The Lagrangian expansion theory technology is essentially a solved problem

Complexity is scaling up…

2) Linear EFT - built of H doublet + higher D ops

$$\mathcal{L} = \mathcal{L}_{SM} + \frac{1}{\Lambda_{\delta L \neq 0}}\mathcal{L}_5 + \frac{1}{\Lambda^2_{\delta B=0}}\mathcal{L}_6 + \frac{1}{\Lambda^2_{\delta B\neq 0}}\mathcal{L}'_6 + \frac{1}{\Lambda^3_{\delta L\neq 0}}\mathcal{L}_7 + \frac{1}{\Lambda^4}\mathcal{L}_8 + \cdots$$

- 

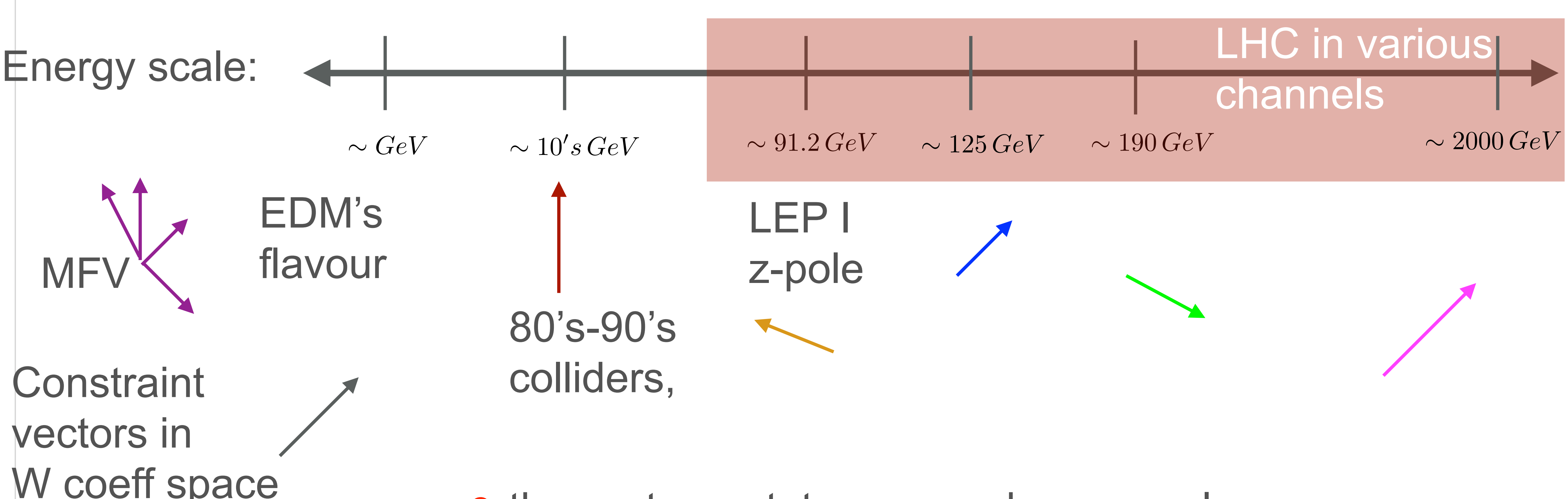
Can reduce the number of relevant parameters to about 50 or so using flavour symmetry and neglecting CP violation, using scaling when near resonances..

- Consistent power counting can also be done.

- WE CAN DO THE RELEVANT GENERAL CASE! AND WE WILL!

Post Modern Discovery Physics

- So what do we do NOW:



- the vectors rotate as you change scale..

- To combine the various constraints consistently take into account they rotate as you change scale.. or introduce theory error.
- Any future discovery has to be projected back on these constraints to check consistency.

Global constraints on dim 6.

Consider LEP I observables:

Observable	Experimental Value	Ref.	SM Theoretical Value	Ref.
$\hat{m}_Z$[GeV]	91.1875 ± 0.0021	[38]	-	-
$\hat{m}_W$[GeV]	80.385 ± 0.015	[39]	80.365 ± 0.004	[40]
σ_h^0 [nb]	41.540 ± 0.037	[38]	41.488 ± 0.006	[41]
Γ_Z[GeV]	2.4952 ± 0.0023	[38]	2.4942 ± 0.0005	[41]
R_ℓ^0	20.767 ± 0.025	[38]	20.751 ± 0.005	[41]
R_b^0	0.21629 ± 0.00066	[38]	0.21580 ± 0.00015	[41]
R_c^0	0.1721 ± 0.0030	[38]	0.17223 ± 0.00005	[41]
A_{FB}^ℓ	0.0171 ± 0.0010	[38]	0.01616 ± 0.00008	[42]
A_{FB}^c	0.0707 ± 0.0035	[38]	0.0735 ± 0.0002	[42]
A_{FB}^b	0.0992 ± 0.0016	[38]	0.1029 ± 0.0003	[42]

arXiv:1311.3107. Chen et al.

arXiv:1501.0280. Petrov et al.

arXiv:1406.6070 Wells,Zhang

arXiv:1404.3667 Ellis et al.

1211.1320 Masso, Sanz

1209.6382 Batell et al.

And Many others…

1308.2803 Pomarol, Riva. 1409.7605 Trott hep-ph/0412166] Han, Skiba
1411.0669 Falkowski, Riva. 1503.07872 Efrati et al. arXiv:1306.4644 Ciuchini et al.

Basic point is that STU is no longer sufficient in general.

Pioneering SMEFT works: Phys.Lett. B265 (1991) 326-334 Grinstein, Wise
hep-ph/0412166 Han, Skiba

Global constraints on dim 6.

Theory error defined by what you neglect in the calculation:

- All perturbative one loop corrections, LO → NLO

$$\Delta^i_{SMEFT}(\Lambda) = \sqrt{\Delta^2_{IFI,O_i} + \Delta^2_P + \Delta^2_{P,II} + \Delta^2_{\mathcal{L}_8} + \Delta^2_{\rm offshell,O_i}}.$$

Radiative corrections,i.e. emission, one loop, redefining input observables, correlations… in SMEFT.

- Higher order dim 8 terms in the SMEFT

$$\Delta^i_{SMEFT}(\Lambda) \simeq \sqrt{N_8}\, x_i \frac{\bar{v}_T^4}{\Lambda^4} + \frac{\sqrt{N_6}\, g_2^2}{16\, \pi^2}\, y_i \log\left[\frac{\Lambda^2}{\bar{v}_T^2}\right] \frac{\bar{v}_T^2}{\Lambda^2}. \quad \text{(roughly)}$$

arXiv:1508.05060 Berthier, Trott

Error is roughly per-mille to percent level for cut off scales of interest. $\Lambda \lesssim 3\mathrm{TeV}$

Global constraints on dim 6.

Recent global SMEFT analysis on 103 observables (pre LHC data).

arXiv:1502.02570, 1508.05060 Berthier, Trott

Currently most comprehensive global fit of pre-LHC data in SMEFT

- LEP pole data + all these measurements below with clear theory errors

B $2 \to 2$ scattering observables at LEP, Tristan, Pep, Petra.

B.1 $\ell^+ \ell^- \to f \bar{f}$ near and far from the Z pole.

B.1.1 Forward-Backward Asymmetries for u, d, ℓ

B.2 Bhabba scattering, $e^+e^- \to e^+e^-$

C Low energy precision measurements

C.1 ν lepton scattering

C.2 ν Nucleon scattering

C.2.1 Neutrino Trident Production

C.3 Atomic Parity Violation

C.4 Parity Violating Asymmetry in eDIS

C.5 Møller scattering

D Universality in β decays

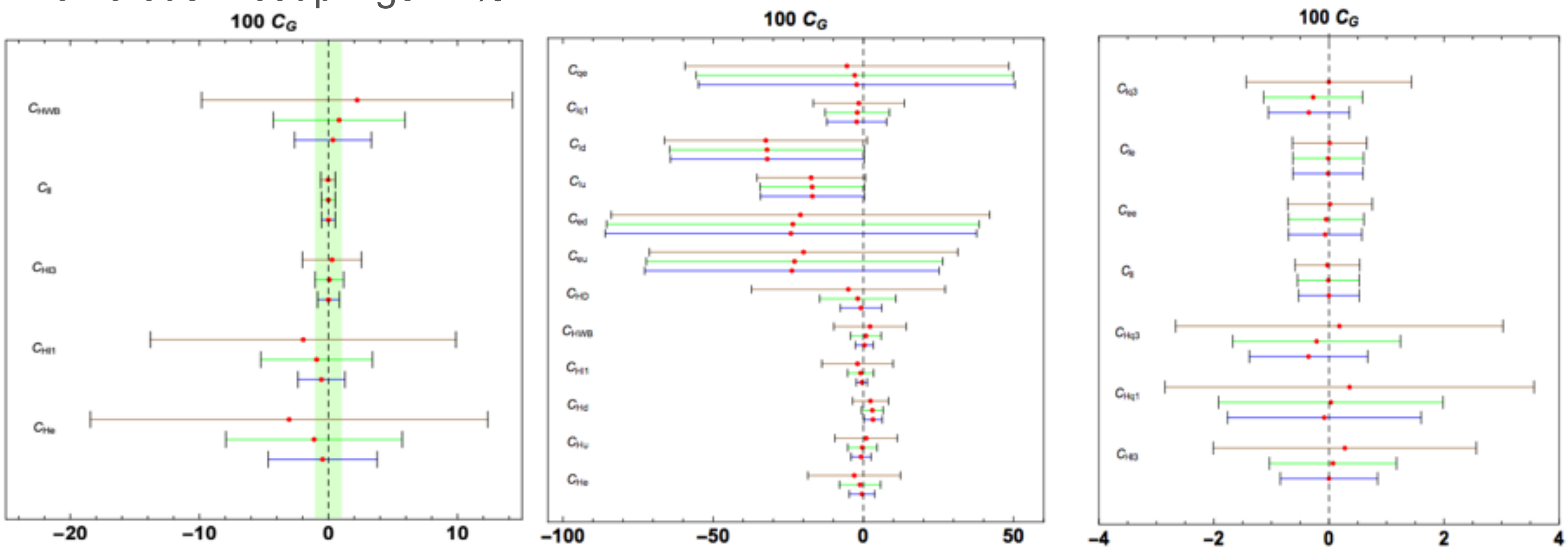
- Global data analysis of data from PEP, PETRA, TRISTAN, SpS, Tevatron, SLAC, LEPI and LEP II

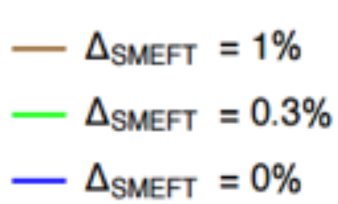
Global constraints on dim 6.

Recent global SMEFT analysis on 103 observables (pre LHC data).

95% CL shown. arXiv:1508.05060 Berthier, Trott

Anomalous Z couplings in %:

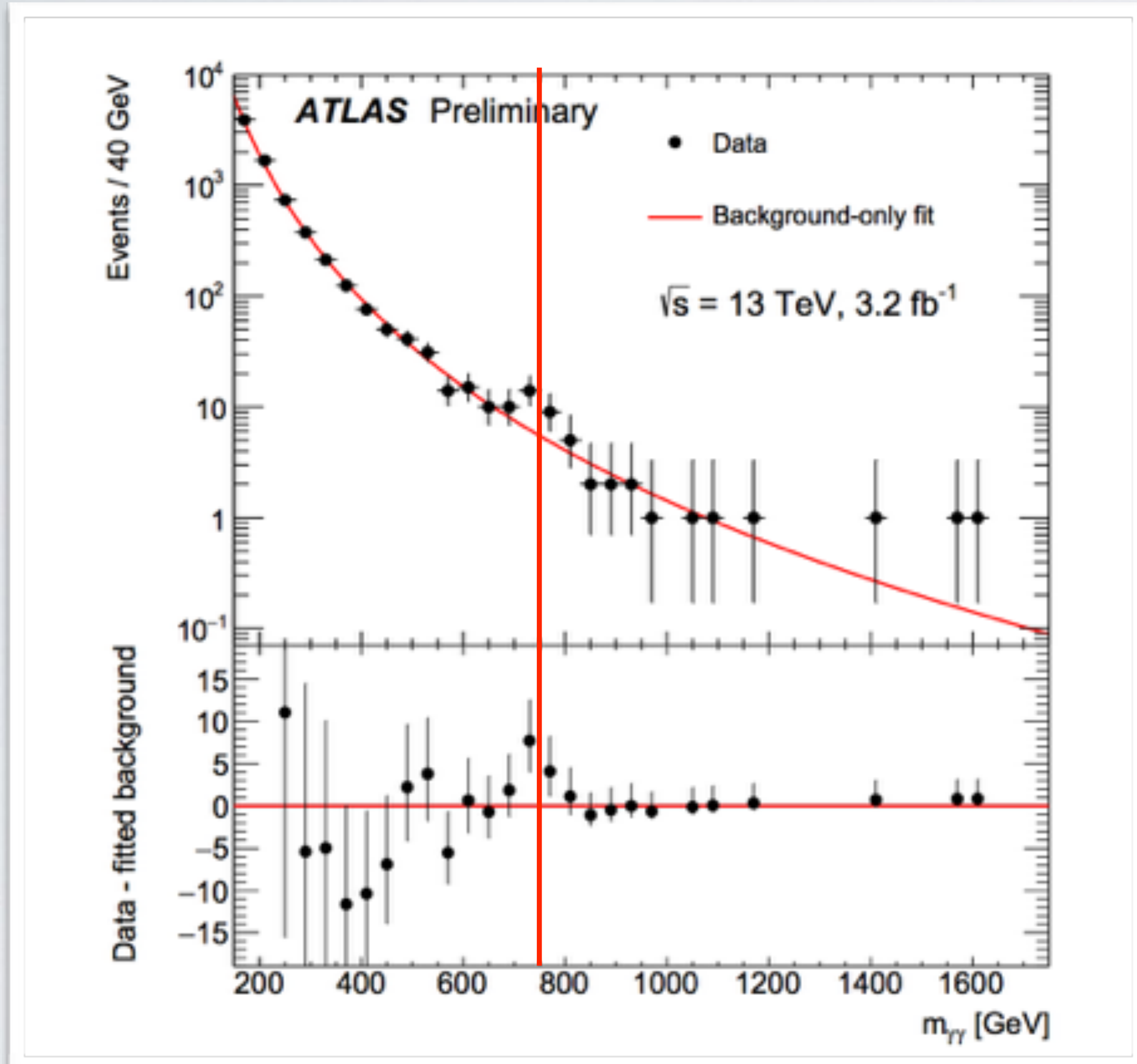


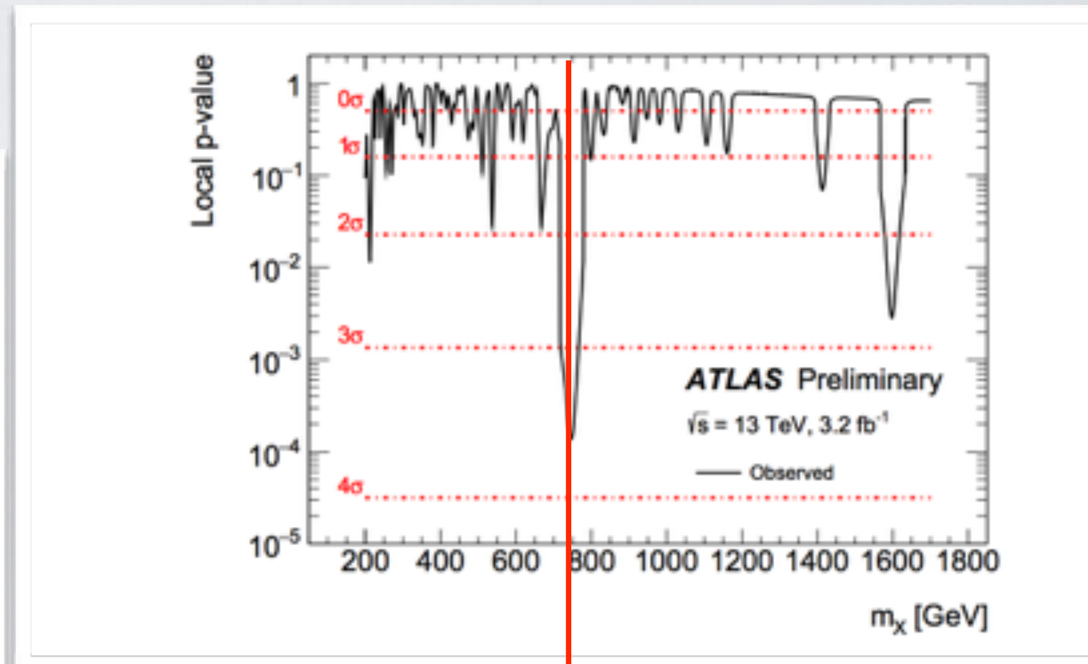


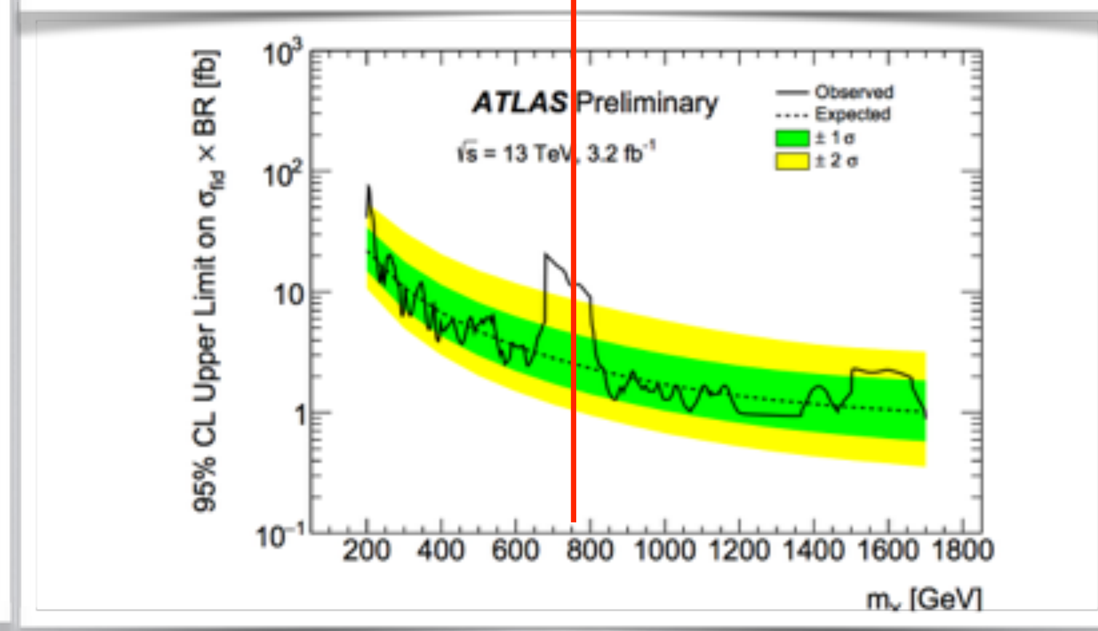
Difference compared to analyses that neglects SMEFT error, some bounds on individual parameters relaxed by factor of 10 or so.

What is this excess? Run2.

- What did we see at 13 TeV?





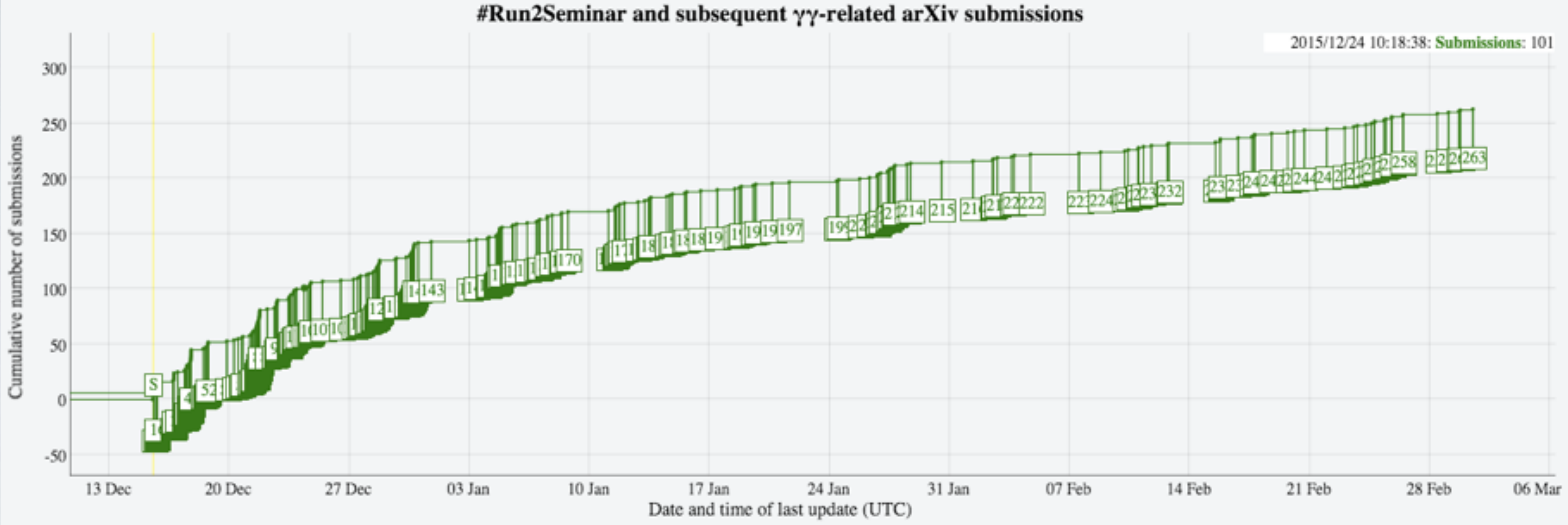


"The data are consistent with the expected background in most of the mass range. The most significant deviation in the observed diphoton invariant mass spectrum is found around 750 GeV, with a global significance of about 2 standard deviations…"

http://cds.cern.ch/record/2114853/files/ATLAS-CONF-2015-081.pdf

How has the theory community responded?

- Picture worth 1000 words:



Common ambulace chasing behavior - see paper
http://arxiv.org/abs/1603.01204
Prediction of 310 papers before it goes away! Failed!

What could it be?

- Possible scenarios:

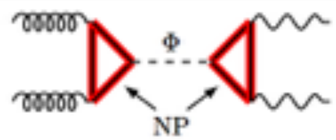
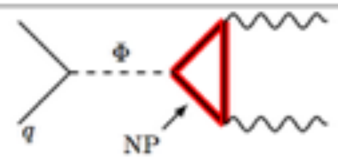
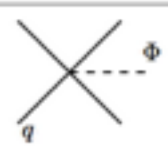
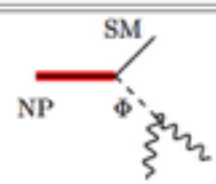
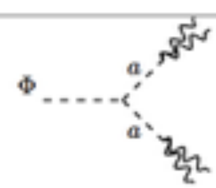
	Gluon fusion through a heavy colored messenger	Section III A
	Non-MVF Yukawa coupling to first generation quarks	Section III B
	Vector boson fusion through a heavy W'	Appendix B
	Cascade decay	Section IV
	Non-resonant kinematic edge providing excess	Section IV
	Decay to two pairs of collimated photons through a Hidden Valley	Section V

TABLE II: Topologies considered in this paper.

http://arxiv.org/pdf/1512.04928.pdf posted 4 hours after (public) announcement

Simplest minimal thing to accommodate possible excess

$$\mathcal{L}_{int} = \frac{c_G\, g_3^2}{\Lambda_g} S\, G^{\mu\nu}\, G_{\mu\nu} + \frac{c_B\, g_1^2}{\Lambda_\gamma} S\, B^{\mu\nu}\, B_{\mu\nu}$$

http://arxiv.org/pdf/1512.06799.pdf Berthier, Cline, Shepherd, MT
6 days after the public talk

Resulting widths:

$$\Gamma(S \to \gamma\gamma) = \frac{4\,\pi\,\alpha_{ew}^2\, m_s^3}{\Lambda_\gamma^2}\, c_B^2, \quad \Gamma(S \to gg) = \frac{32\,\pi\,\alpha_s^2\, m_s^3}{\Lambda_g^2}\, c_G^2.$$

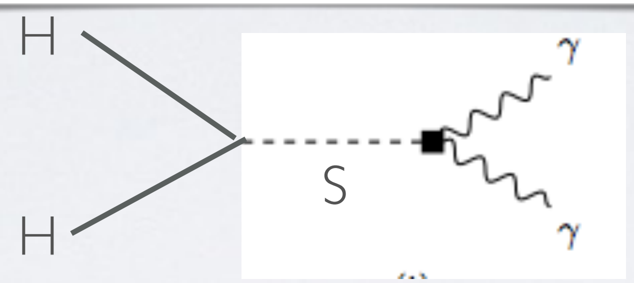
Anomaly related to parameters as:

$$\frac{\Delta\sigma(pp \to \gamma\gamma)}{8[fb]} \left(\frac{\Gamma_s}{45\,\mathrm{GeV}}\right) \simeq 6546 \left(\frac{m_s^2\, c_B^2}{\Lambda_\gamma^2}\right) \left[\left(\frac{m_s^2\, c_G^2}{\Lambda_g^2}\right) + 2.4 \times 10^{-7} \left(\frac{m_s^2\, c_B^2}{\Lambda_\gamma^2}\right)\right]$$

What about the other low energy measurements?

- Integrate out S:

$$\mathcal{L}_V = -\lambda_{SM}\left(H^\dagger H - \frac{1}{2}v^2\right)^2 - \frac{m_s^2}{2}S^2 + \frac{\kappa}{4!}S^4 + \lambda\,\Lambda_c\,S\,H^\dagger H + \lambda_2\,\Lambda_c\,S^3 + \lambda_3\,S^2\,(H^\dagger H) + \cdots$$



$$\mathcal{L} = \mathcal{L}_{SM} + \frac{C_{HG}(m_s)\,g_3^2}{\Lambda^2} H^\dagger\,H\,G^{\mu\nu}\,G_{\mu\nu} + \frac{C_{HB}(m_s)\,g_1^2}{\Lambda^2} H^\dagger\,H\,B^{\mu\nu}\,B_{\mu\nu},$$

where

$$\frac{C_{HG}(m_s)}{\Lambda^2} = \frac{c_G\,\lambda}{m_s^2}\,\frac{\Lambda_c}{\Lambda_g}, \qquad \frac{C_{HB}(m_s)}{\Lambda^2} = \frac{c_B\,\lambda}{m_s^2}\,\frac{\Lambda_c}{\Lambda_\gamma}.$$

These are the contributions due to “mixing” to the dim 6 ops.

These are the results at the scalar mass scale.

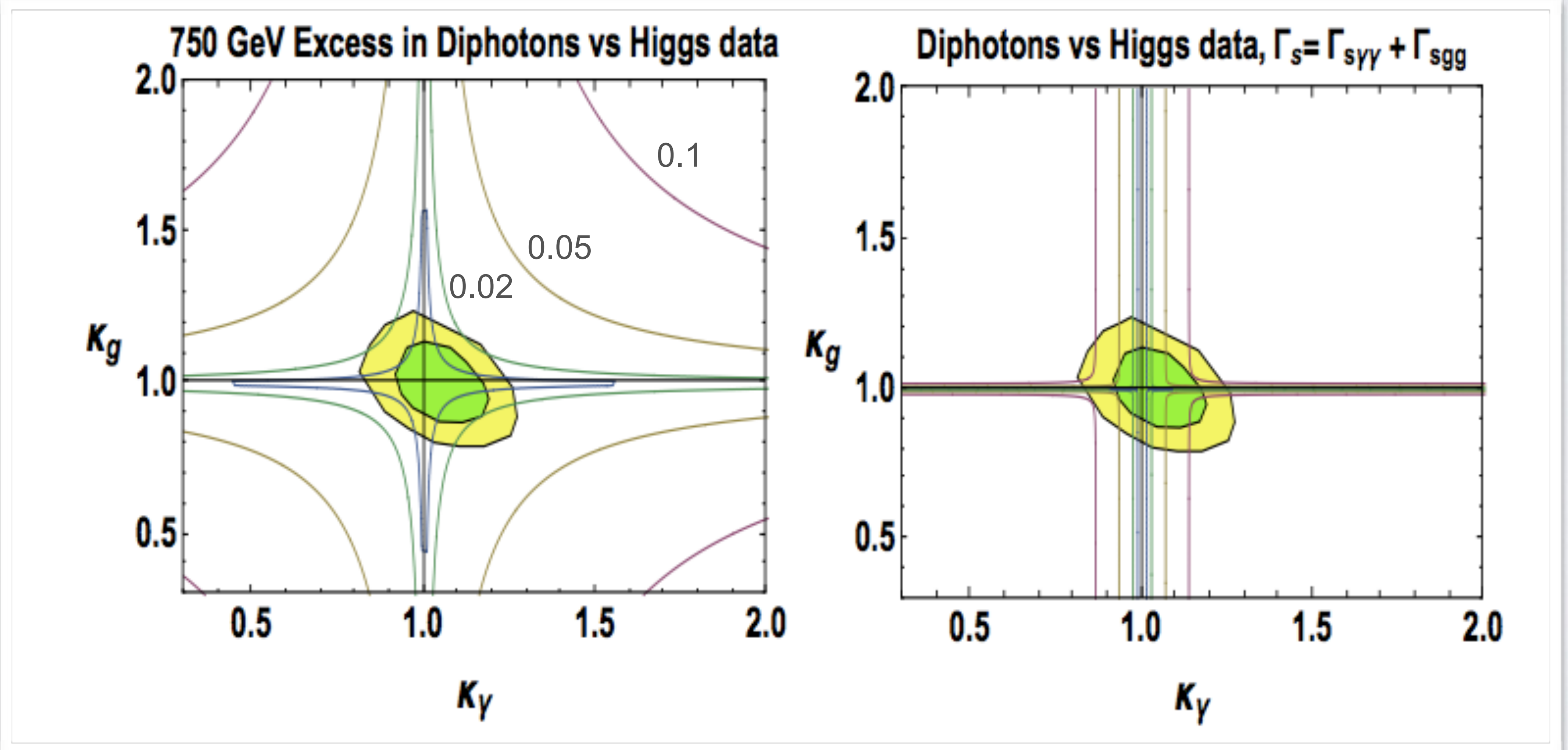
How about the Higgs - perturbed too much?

- Effects on Higgs loop couplings

$$\mathcal{O} = \frac{\Delta\sigma(pp \to S \to \gamma\gamma)}{8[fb]} \left(\frac{\Gamma_s}{45\,\mathrm{GeV}}\right) \left(\frac{\lambda\,\Lambda_c}{N \times 750\,\mathrm{GeV}}\right)^4,$$

$$\mathcal{O} \simeq 0.0005\,(\kappa_\gamma - 1)^2 \left[(\kappa_g - 1)^2 + 4.2 \times 10^{-6}\,(\kappa_\gamma - 1)^2\right].$$

30% or so deviations allowed in these couplings (see plot)



Wee bit of unnaturalness. Not a big deal.

http://arxiv.org/pdf/1512.06799.pdf Berthier, Cline, Shepherd, MT
6 days after the public talk

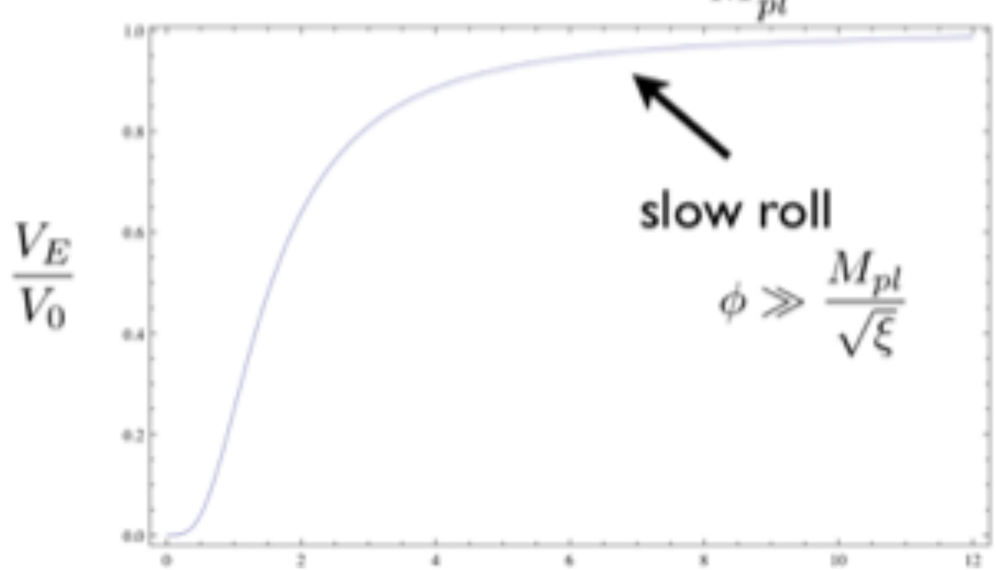
These EFT's matter in Higgs inflation.

- The basic idea: $\mathcal{L}_{HI} = \mathcal{L}_{SM} - \sqrt{-g}\left[\frac{m_p^2}{2} + \xi\, H^\dagger H\right] R + \cdots$

Spokoiny Phys Lett B 147B 39 (1984)
Salopek, Bond, Bardeen Phys Rev D 40 1753 (1989)
Bezrukov, Shaposhnikov Phys Lett B 659, 703 (2008) arXiv:0710.3755

- Flatten the SM potential with a large non-minimal coupling.
  Weyl rescaling to the Einstein frame:

$\hat{g}_{\mu\nu} = \Omega^2 g_{\mu\nu}$ where $\Omega^2 = 1 + \frac{\xi\,\phi^2}{M_{pl}^2}$ and $V_E(\phi) = \frac{V(\phi)}{(1 + \frac{\xi\,\phi^2}{M_{pl}^2})^2}$



- LARGE coupling
- Small coupling uses inflection point.

What is the cut off scale?

- Cut off scales easy to understand (goldstone scattering)

$$\mathcal{A}(\sigma^i\,\sigma^j \to \sigma^k\,\sigma^l) = \left(1 - (a_{sm} + \delta a)^2\right) \frac{s\,\delta^{ij}\,\delta^{kl} + t\,\delta^{ik}\,\delta^{jl} + u\,\delta^{il}\,\delta^{jk}}{\bar{\chi}^2},$$

$$= \frac{2\,\xi^2}{M_{pl}^2}\left(s\,\delta^{ij}\,\delta^{kl} + t\,\delta^{ik}\,\delta^{jl} + u\,\delta^{il}\,\delta^{jk}\right), \quad \text{small field}$$

$$\mathcal{A}(\sigma^i\,\sigma^j \to \sigma^k\,\sigma^l) = \frac{\xi}{M_p^2}\left[s\,\delta^{ij}\,\delta^{kl} + t\,\delta^{ik}\,\delta^{jl} + u\,\delta^{il}\,\delta^{jk}\right], \quad \text{large field}$$

- Between the scales the cut off scale rises as $\Lambda \sim 4\,\pi\bar{\chi}$

  As in a theory with un-higgs massive vectors.

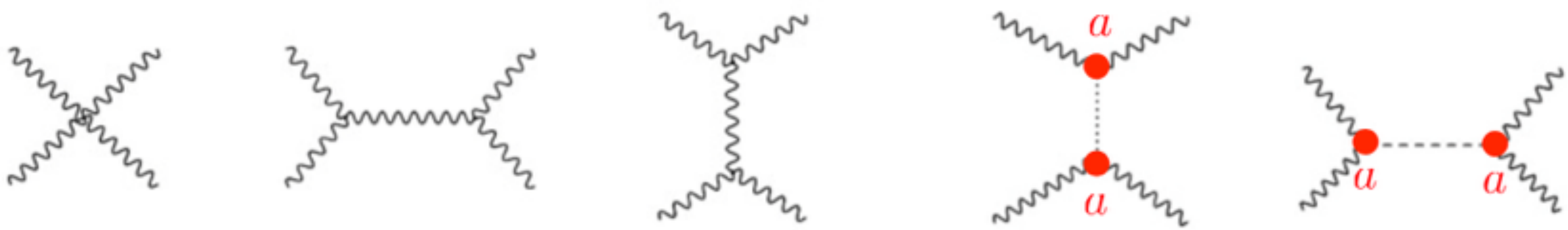
- Sorted out in 0902.4465, 1002.2730 Burgess, Lee, MT
  0903.0355, Barbon, Espinosa
  1008.5157, Bezrukov et al. (the key analysis on background dependence)

The physics is the non-linear theory

- Cut off scales easy to understand (goldstone scattering)

$$\mathcal{A}(\sigma^i\,\sigma^j \to \sigma^k\,\sigma^l) = \left(1-(a_{sm}+\delta a)^2\right)\frac{s\,\delta^{ij}\,\delta^{kl}+t\,\delta^{ik}\,\delta^{jl}+u\,\delta^{il}\,\delta^{jk}}{\bar{\chi}^2},$$
$$= \frac{2\,\xi^2}{M_{pl}^2}\left(s\,\delta^{ij}\,\delta^{kl}+t\,\delta^{ik}\,\delta^{jl}+u\,\delta^{il}\,\delta^{jk}\right), \quad \text{small field}$$

$$\mathcal{A}(\sigma^i\,\sigma^j \to \sigma^k\,\sigma^l) = \frac{\xi}{M_p^2}\left[s\,\delta^{ij}\,\delta^{kl}+t\,\delta^{ik}\,\delta^{jl}+u\,\delta^{il}\,\delta^{jk}\right], \quad \text{large field}$$

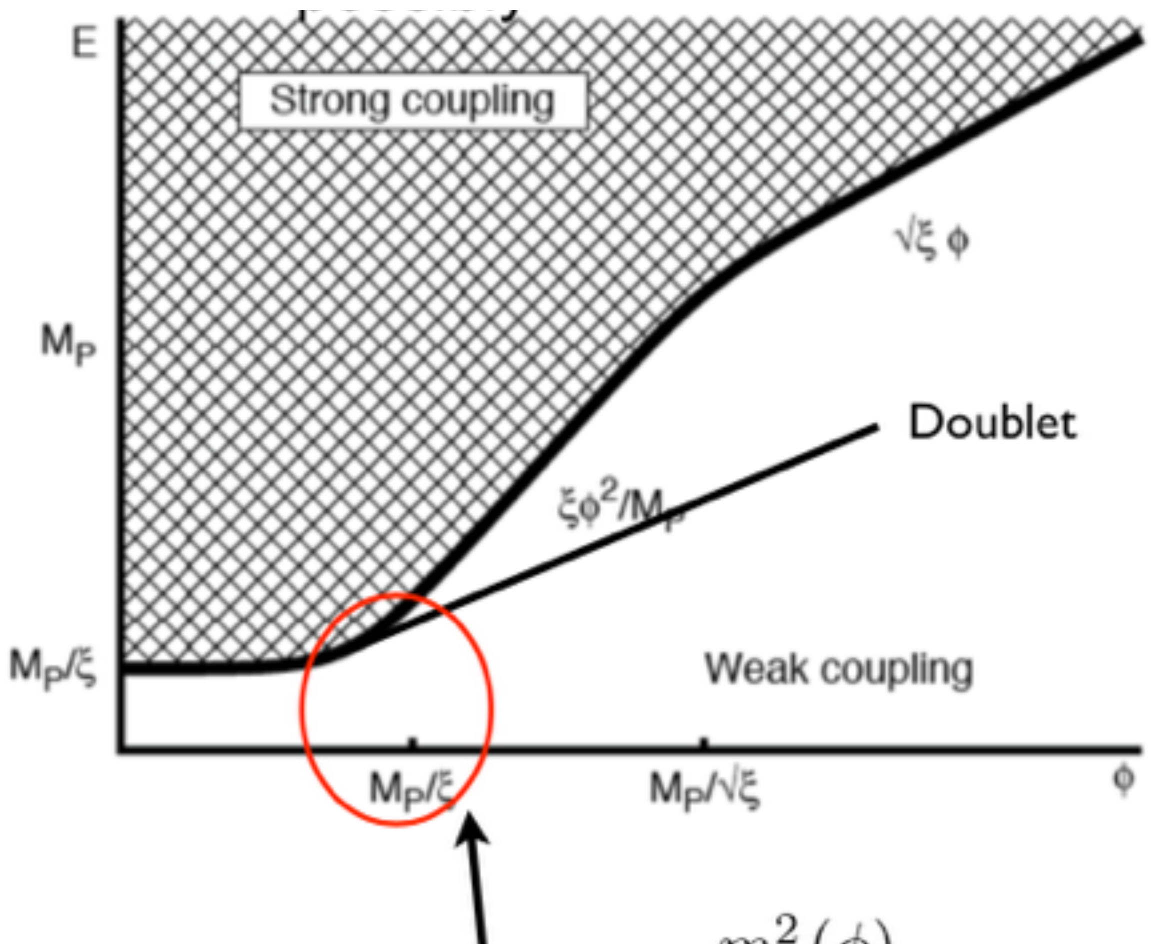


- Exactly the scattering physics of the nonlinear realization Higgs EFT.

Higgs Inflation predictions..

- Should add all higher D operators suppressed by this scale by the usual rules of EFT.

1008.5157, Bezrukov et al.



- Above the scale M_{pl}/ξ treat this as a nonlinear chiral EW theory

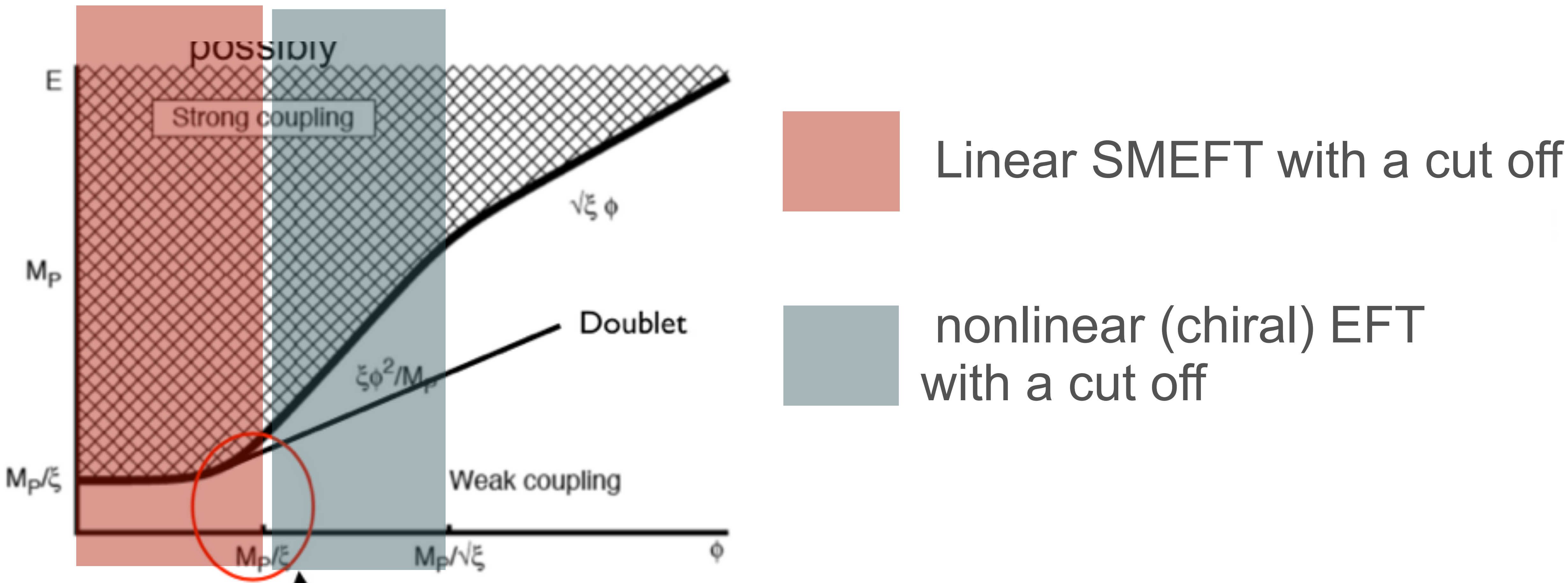
F. Bezrukov and M. Shaposhnikov, JHEP 0907 (2009)[arXiv:0904.1537]; F. L. Bezrukov, A. Magnin and M. Shaposhnikov, Phys. Lett. B 675 (2009) [arXiv:0812.4950].

S. Dutta, K. Hagiwara, Q. S. Yan and K. Yoshida, Nucl. Phys. B 790 (2008) 111 doi:10.1016/j.nuclphysb.2007.08.017 [arXiv:0705.2277 [hep-ph]].

- Right here $\frac{m_h^2(\phi)}{\Lambda^2(\phi)} \to 1$ threshold terms in the RGE introduce UV sensitivity

Higgs Inflation predictions..

- Should add all higher D operators suppressed by this scale by the usual rules of EFT.



- Right here $\dfrac{m_h^2(\phi)}{\Lambda^2(\phi)} \to 1$ threshold terms in the RGE introduce UV sensitivity

are UV sensitive in this manner.

1308.2627 Jenkins, Manohar, MT

- Threshold terms in the linear SMEFT - in a flat background:

$$\mu\frac{d}{d\mu}\lambda = \frac{m_H^2}{16\pi^2}\Big[12C_H + \left(-32\lambda + \frac{10}{3}g_2^2\right)C_{H\Box} + \left(12\lambda - \frac{3}{2}g_2^2 + 6g_1^2 y_H^2\right)C_{HD} + 2\eta_1 + 2\eta_2$$
$$+ 12g_2^2 c_{F,2} C_{HW} + 12 g_1^2 y_H^2 C_{HB} + 6 g_1 g_2 y_H C_{HWB} + \frac{4}{3}g_2^2 C^{(3)}_{\underset{tt}{Hl}} + \frac{4}{3}g_2^2 N_c C^{(3)}_{\underset{tt}{Hq}}\Big],$$

$$\mu\frac{d}{d\mu}m_H^2 = \frac{m_H^4}{16\pi^2}\left[-4C_{H\Box} + 2C_{HD}\right],$$

$$\mu\frac{d}{d\mu}[Y_u]_{rs} = \frac{m_H^2}{16\pi^2}\Big[3C^*_{\underset{sr}{uH}} - C_{H\Box}[Y_u]_{rs} + \frac{1}{2}C_{HD}[Y_u]_{rs} - [Y_u]_{rt}\left(C^{(1)}_{\underset{ts}{Hq}} + 3C^{(3)}_{\underset{ts}{Hq}}\right) + C_{\underset{rt}{Hu}}[Y_u]_{ts}$$
$$- C_{\underset{rt}{Hud}}[Y_d]_{ts} - 2\left(C^{(1)*}_{\underset{sptr}{qu}} + c_{F,3}C^{(8)*}_{\underset{sptr}{qu}}\right)[Y_u]_{tp} - C^{(1)*}_{\underset{ptsr}{lequ}}[Y_e^*]_{tp} + N_c C^{(1)*}_{\underset{srpt}{quqd}}[Y_d]^*_{tp}$$
$$+ \frac{1}{2}\left(C^{(1)*}_{\underset{prst}{quqd}} + c_{F,3}C^{(8)*}_{\underset{prst}{quqd}}\right)[Y_d]^*_{tp}\Big],$$

$$\mu\frac{dg_3}{d\mu} = -4\frac{m_H^2}{16\pi^2}g_3 C_{HG}, \qquad \mu\frac{dg_2}{d\mu} = -4\frac{m_H^2}{16\pi^2}g_2 C_{HW}, \qquad \mu\frac{dg_1}{d\mu} = -4\frac{m_H^2}{16\pi^2}g_1 C_{HB},$$
$$\mu\frac{d}{d\mu}\theta_3 = -\frac{4m_H^2}{g_3^2}C_{H\tilde{G}}, \qquad \mu\frac{d}{d\mu}\theta_2 = -\frac{4m_H^2}{g_2^2}C_{H\tilde{W}}, \qquad \mu\frac{d}{d\mu}\theta_1 = -\frac{4m_H^2}{g_1^2}C_{H\tilde{B}},$$

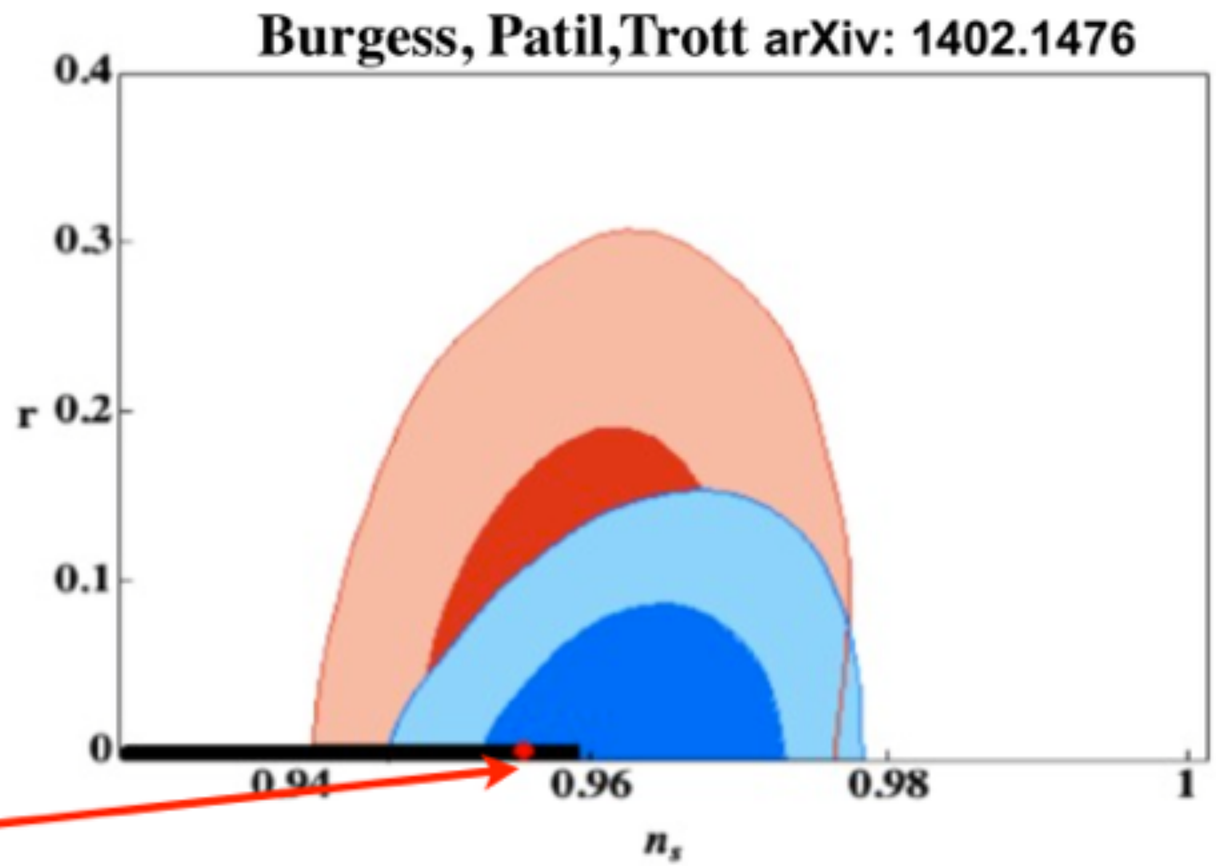
- Extra dependence on ξ and Hubble parameter in EOM $\propto \dot{\mathcal{H}} + 3\,\mathcal{H}^2$

The picture of the UV dependence

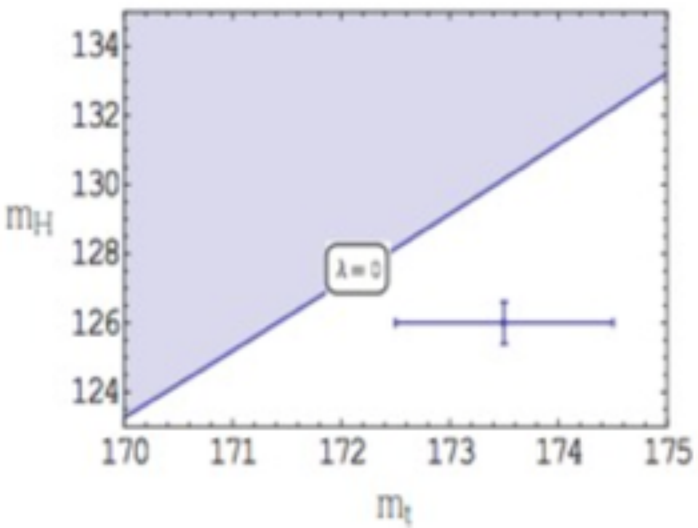
- NOT a predictive scenario. We can't know it is right by measurements of this form.

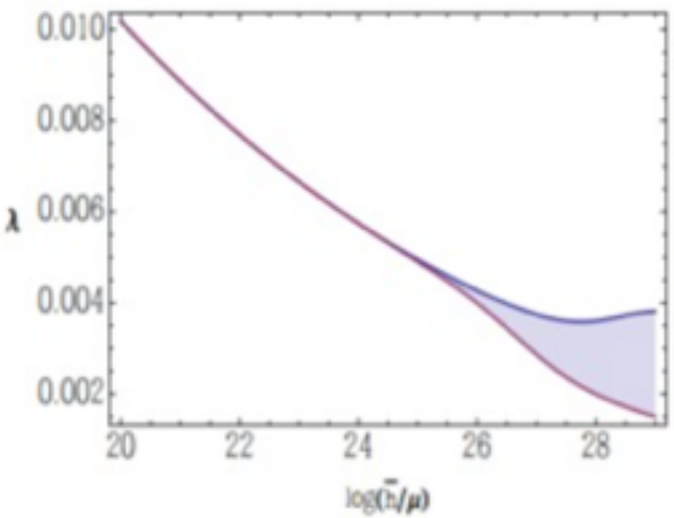
—— what ~~you~~ we get due to the threshold terms in the RGE smearing predictions

Usual prediction for HI.



also...





Conclusions

- Discovered Higgs like scalar in Run 1 has very SM like properties implying cut off scale parametrically separated from the EW scale
- Properties are already know precisely enough to massacre models and inform speculation about the 750 GeV excess.
- EFT formalisms under rapid development have applications to the Higgs inflation scenario.
- Is it a period or a ? in the title - you decide!