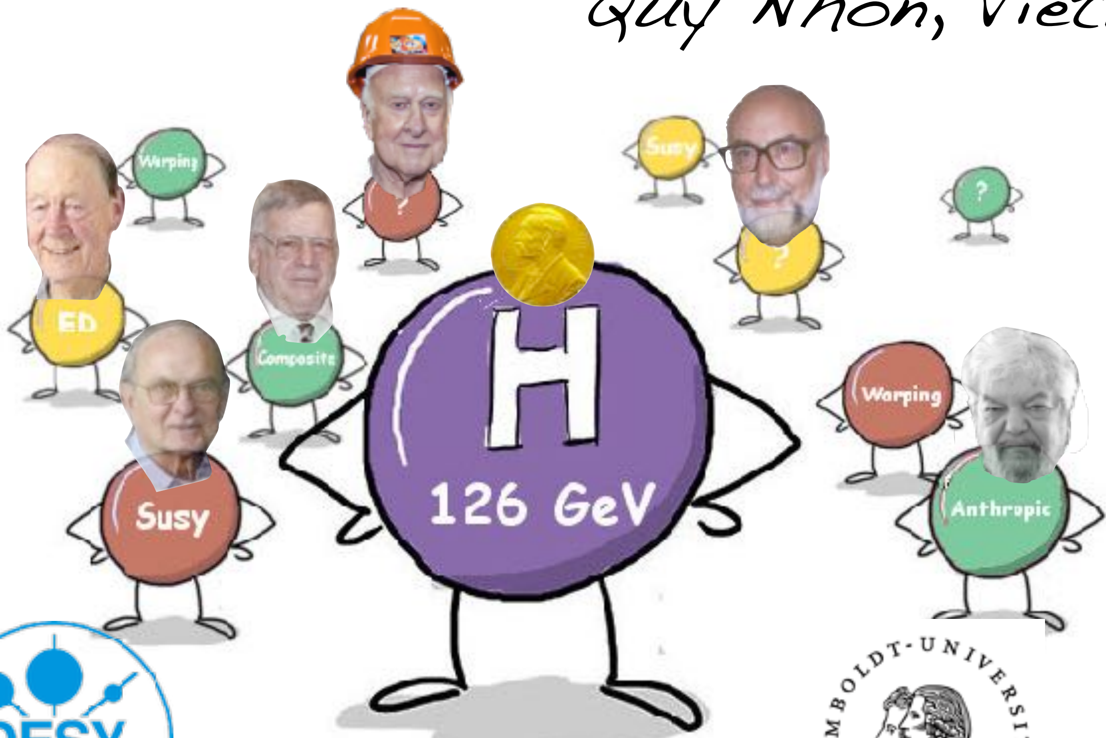
Higgs and BSM Physics

AEPSHEP 2018

Quy Nhon, Vietnam

Lecture 2/4



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Outline

▢ Lecture #1

- From Fermi theory to the Standard Model
- Chirality, fermion masses, spontaneous symmetry breaking
- Custodial symmetry
- Gauge boson masses, unitarity and the Higgs boson

▢ Lecture #2

- Higgs phenomenology (decay and production at colliders)
- Higgs quantum potential (vacuum (meta)stability, naturalness)
- Hierarchy problem

▢ Lecture #3

- Supersymmetry
- Composite Higgs
- Extra dimensions

▢ Lecture #4

- Connections particle physics-cosmology
- Quantum gravity: landscape vs swampland
- BSM searches beyond colliders: AMO, EDMs, nñ, GW, PBH

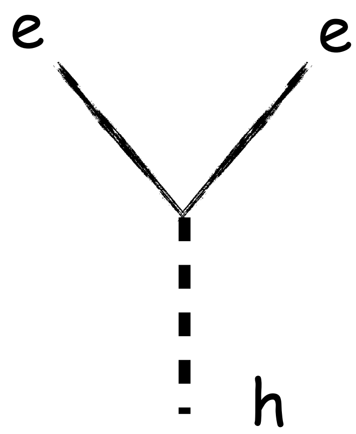
SM Higgs phenomenology

Higgs boson at the LHC

producing a Higgs boson is a rare phenomenon
since its interactions with particles are proportional to masses
and ordinary matter is made of light elementary particles

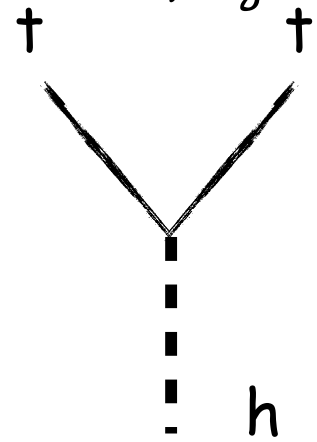
NB: the proton is not an elementary particle,
its mass doesn't measure its interaction with the Higgs substance

From electrons



probability ~ 10^{-11}

From top quarks



probability ~ 1

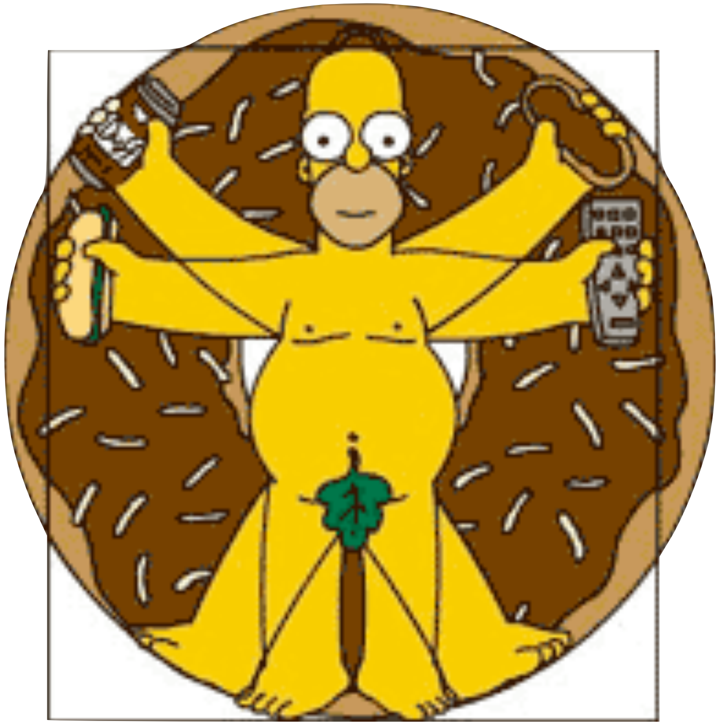
but no top quark at our disposal

Higgs boson at the LHC

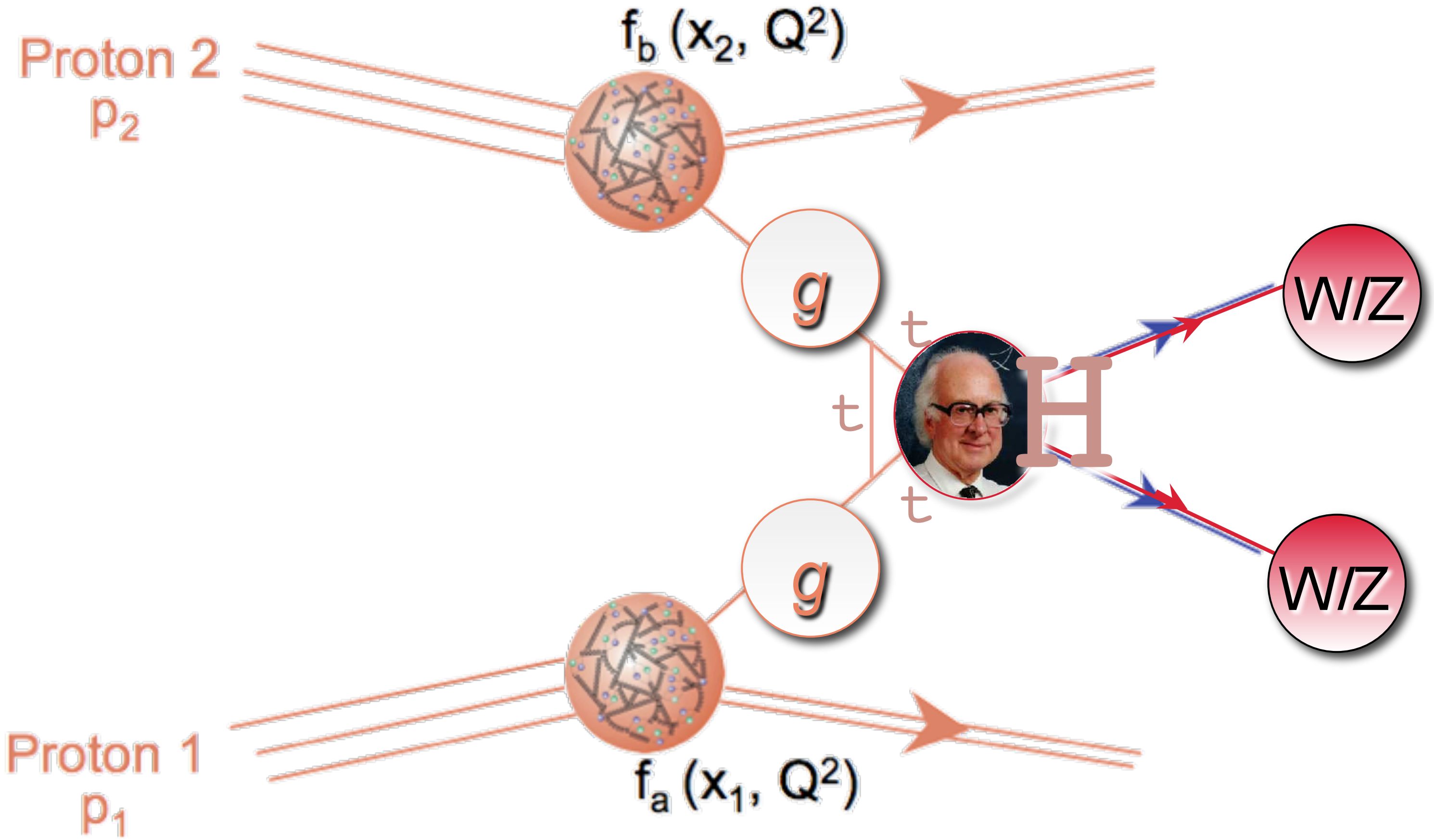
Difficult task

Homer Simpson's principle of life:

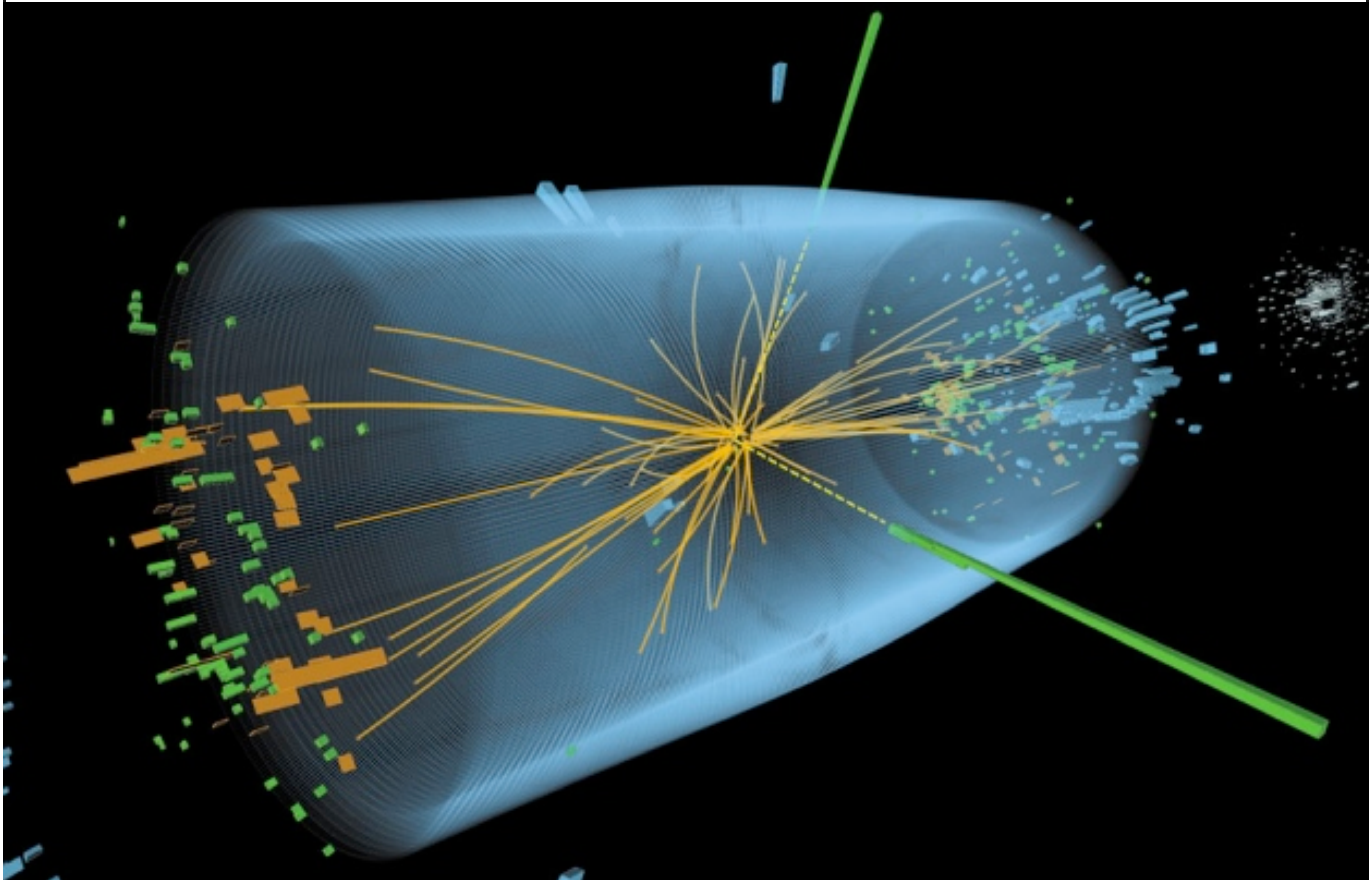
If something's hard to do, is it worth doing?



Higgs boson at the LHC



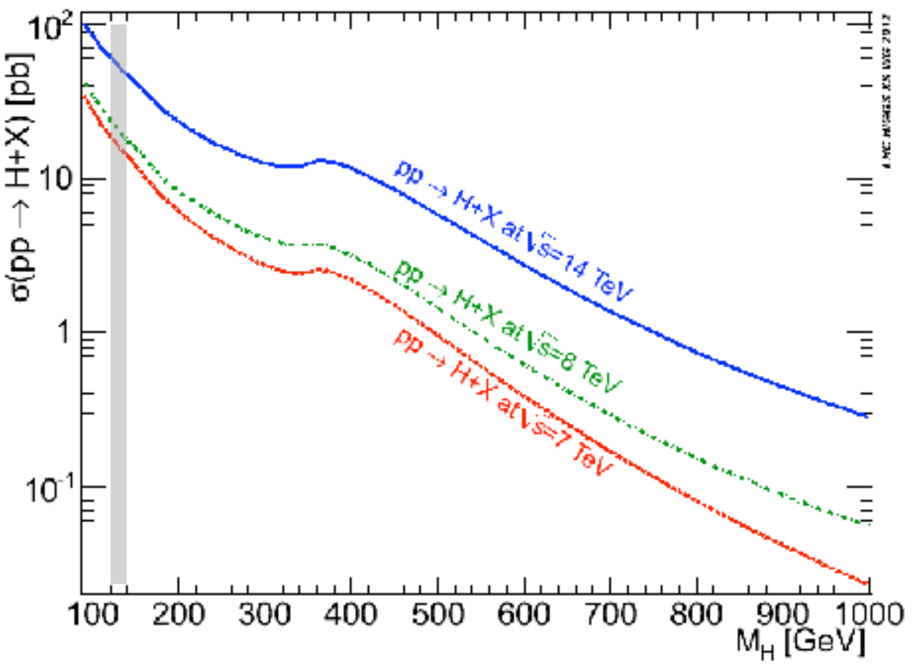
Higgs boson at the LHC



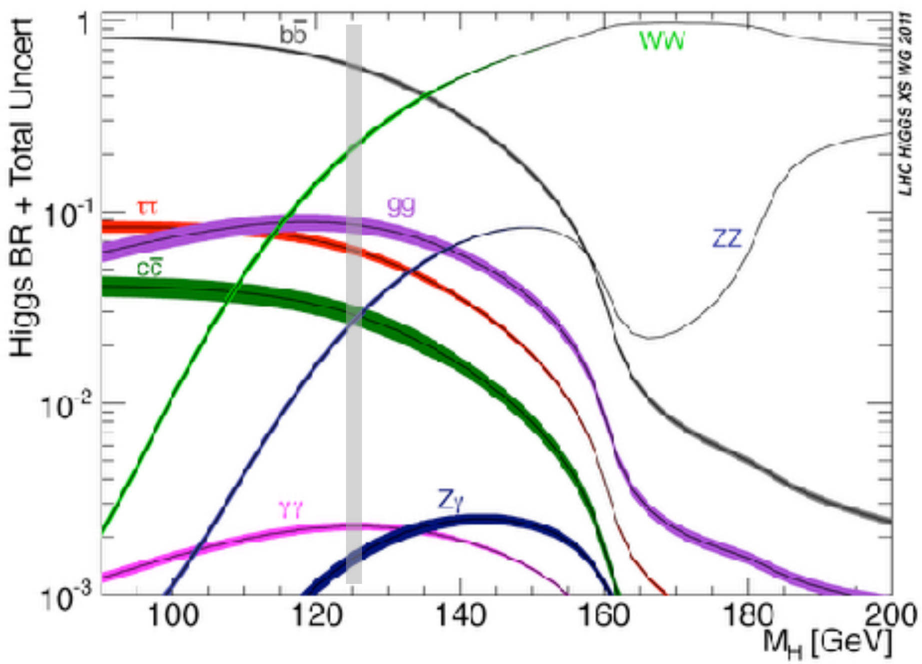
Higgs boson at the LHC

$\sigma \sim 10$ pb $\Leftrightarrow 10^6$ events for L=100 fb^{-1}

Higgs production



Higgs decay

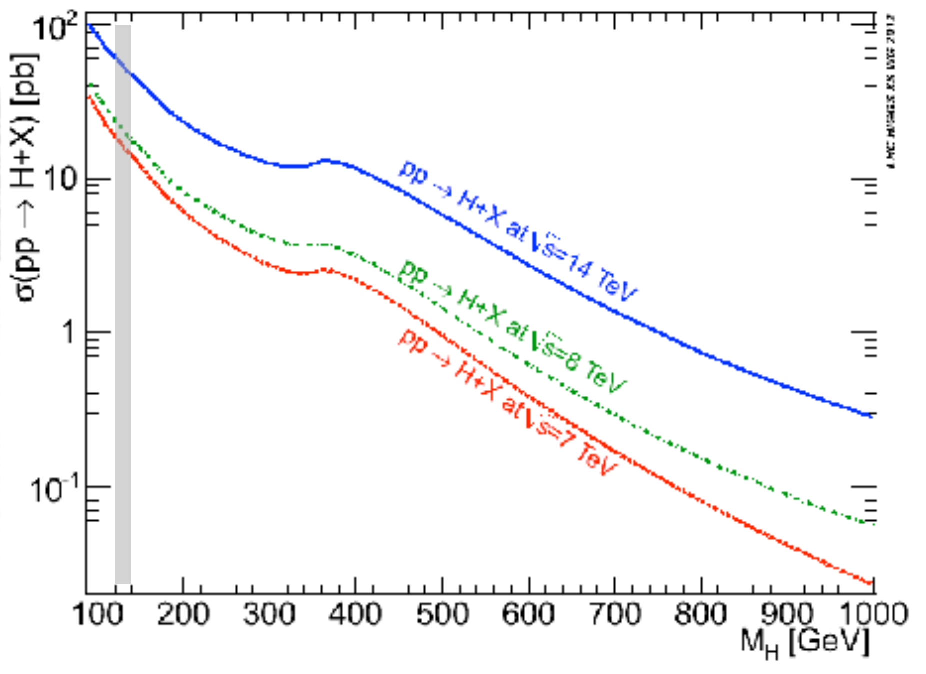


The LHC has produced 10^6 Higgs bosons out of 10^{17} pp collisions

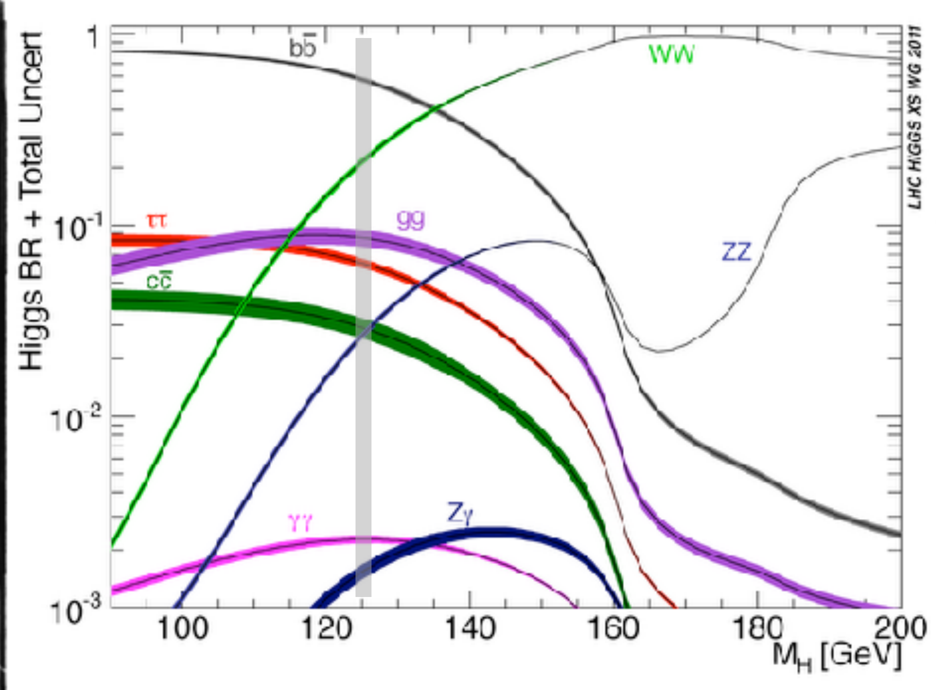
Higgs boson at the LHC

Exercise: The instantaneous luminosity is $10^{34}cm^{-2}s^{-1}$. The LHC beams cross every 25ns. The total cross-section in 0.1b. What is the collision rate? One collision occupies about 1MB on disk. Given that you cannot record data faster than 1GB/s, what should be the trigger rate?

Higgs production



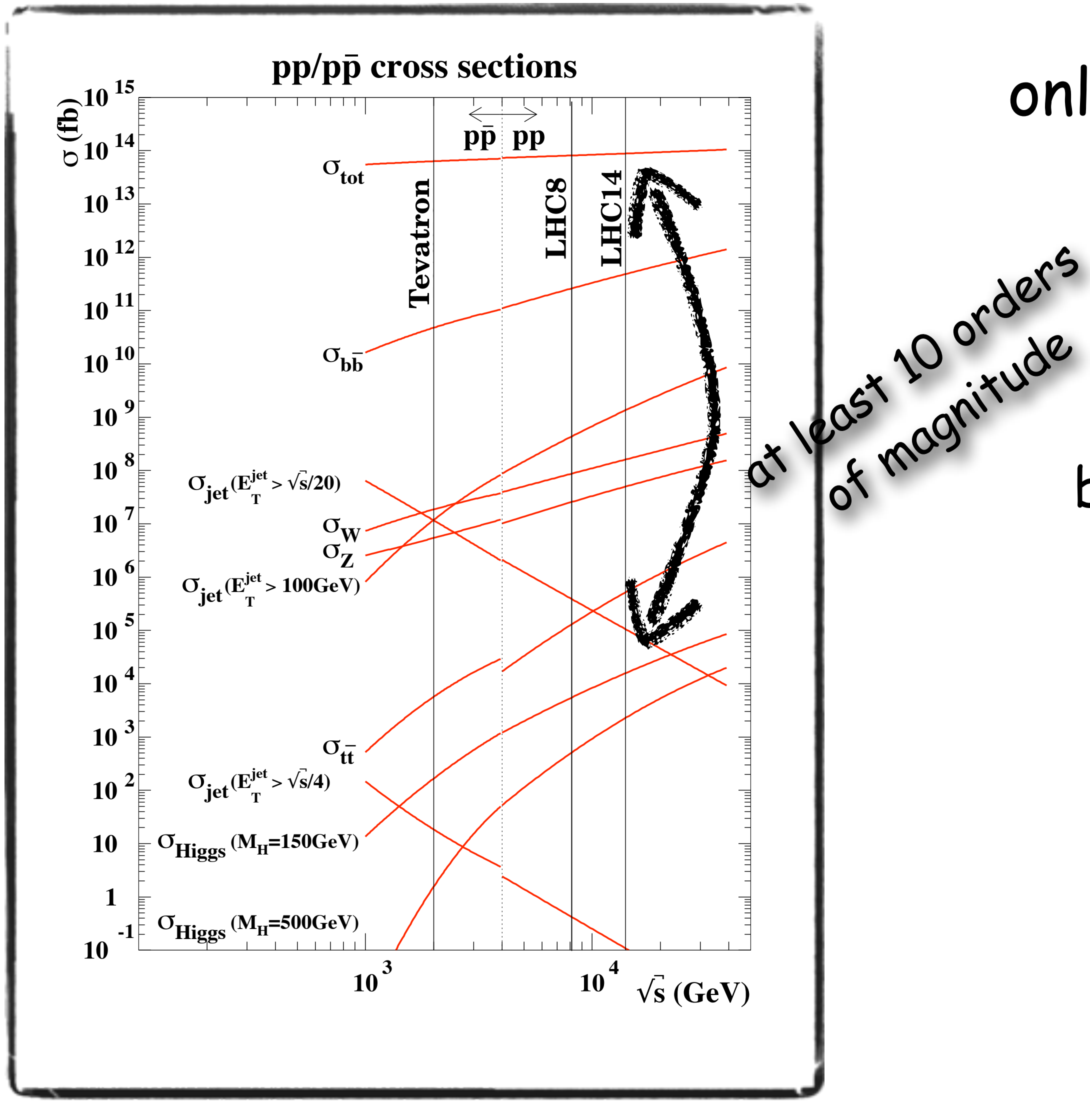
Higgs decay



The LHC has produced 10^6 Higgs bosons out of 10^{17} pp collisions

SM Higgs @ LHC

The production of a Higgs is wiped out by QCD background



only 1 out of 100 billions events are "interesting"

(for comparison, Shakespeare's 43 works contain only 884,429 words in total)

furthermore many of the background events furiously look like signal events

SM Higgs @ LHC

The production of a Higgs is wiped out by QCD background

only 1 out of 100 billions events are "interesting"

(for comparison, Shakespeare's 43 works contain only 884,429 words in total)

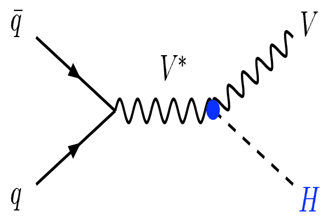
furthermore many of the background events furiously look like signal events

... like finding the paper you are looking for in (10[8] copies of) John Ellis' office

SM Higgs Production

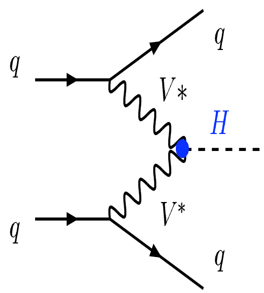
(see for instance A. Djouadi, hep-ph/0503172)

Higgs-strahlung



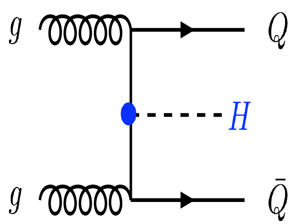
$\propto$ 1/s: Tevatron, LHC

Vector boson fusion

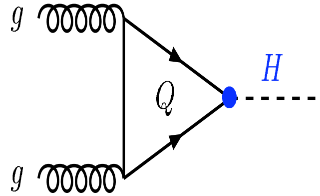


forward jet tagging
central jet veto
small hadronic activity

QQ associated production

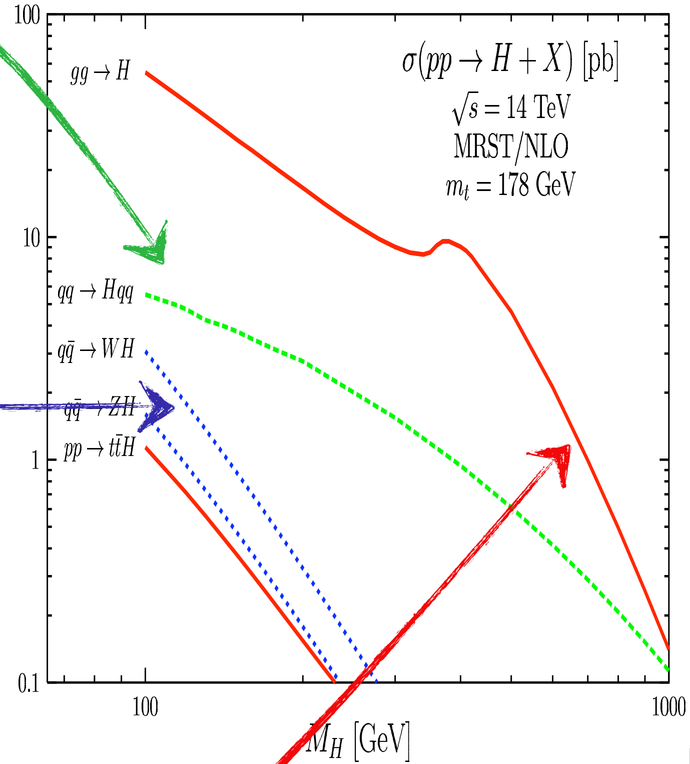


Gluon fusion



single final state
large NLO enhancement

Higgs production @ LHC

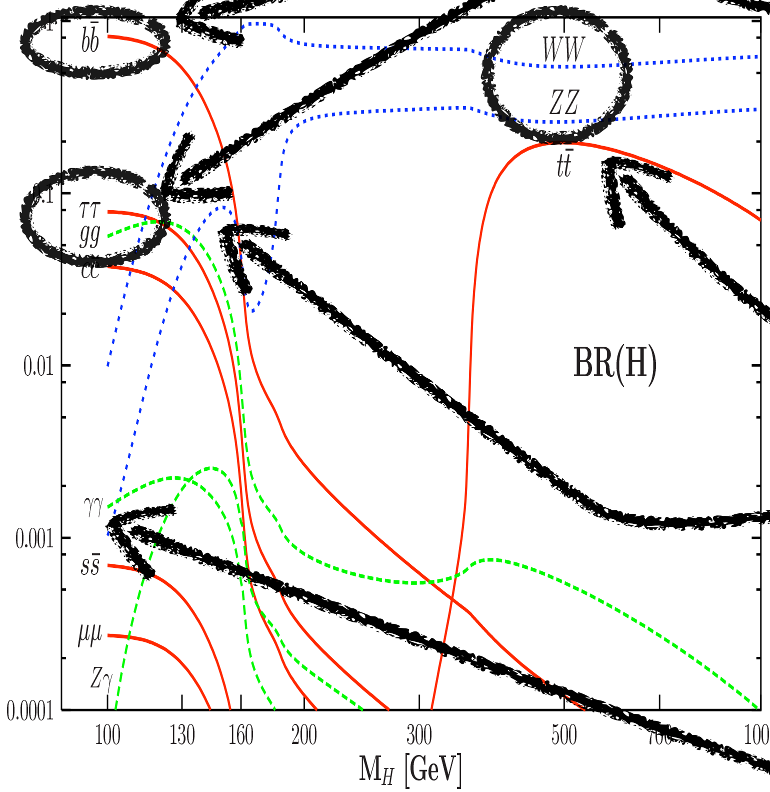


SM Higgs Decays

Higgs couples proportionally to masses:

it decays into the heaviest particle available by phase space

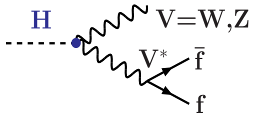
BRs



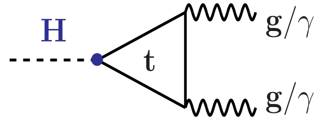
light Higgs

heavy Higgs

decay into VV below threshold

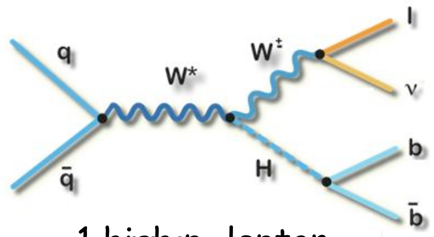


decay into massless particles (γ, gluons) at 1-loop

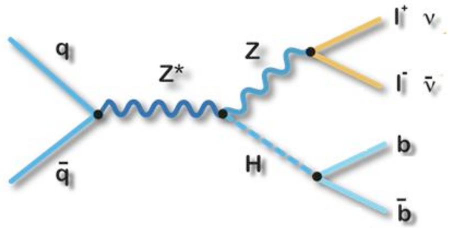


(SM) Higgs Searches @ Tevatron

- Low Mass Higgs

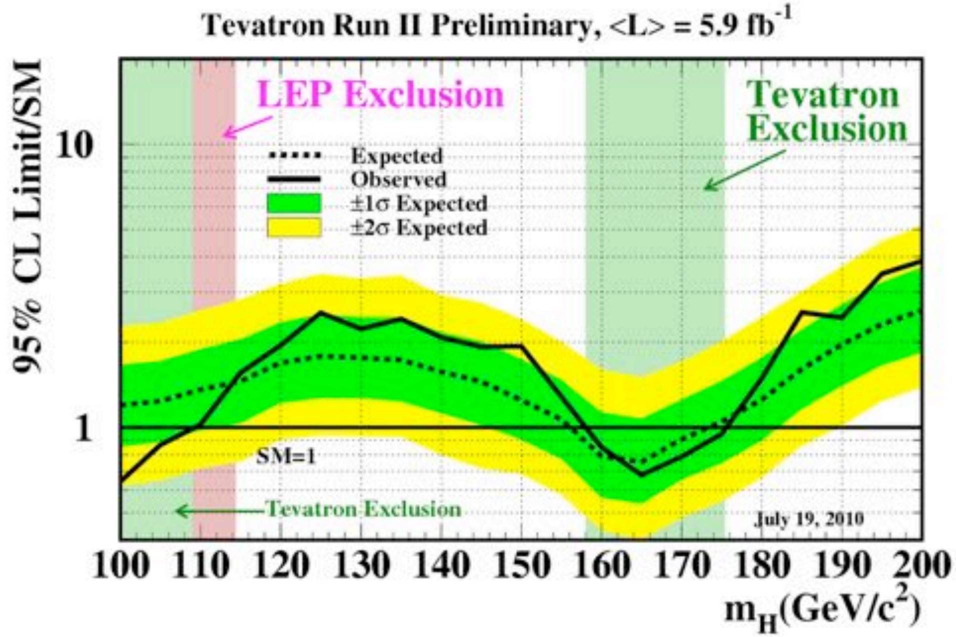


1 high p_T lepton
$\not{E}_T$
2 b-jets

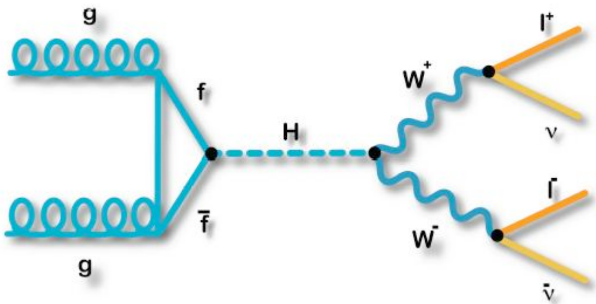


2 high p_T leptons/high $\not{E}_T$
2 b-jets

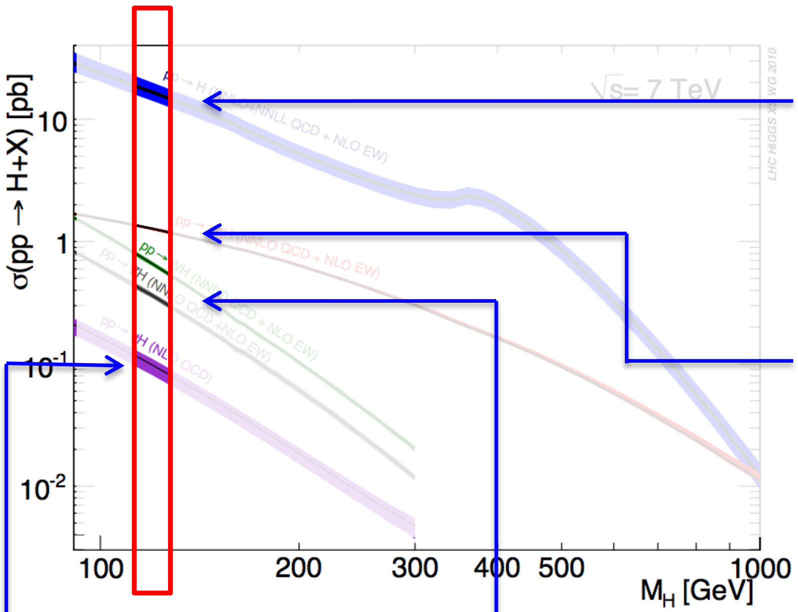
Issues:
- lepton identification
- b-tagging performance
- dijet mass resolution

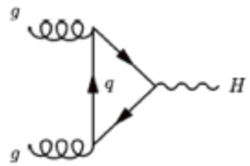


- High Mass Higgs



(SM) Higgs Searches @ the LHC





- Gluon fusion process :

Dominant process known at NNnLO TH uncertainty ~O(10%)

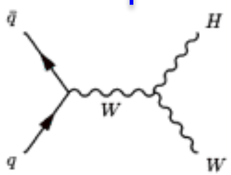
~0.5 M events produced!

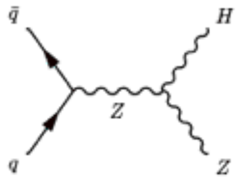
- Vector Boson Fusion :

known at NLO TH uncertainty ~O(5%)

Distinctive features with two forward jets and a large rapidity gap

~40 k events produced!



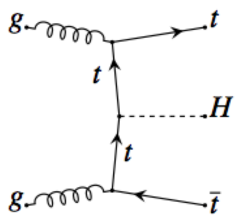


- W and Z Associated Production :

known at NNLO TH uncertainty ~O(5%)

Very distinctive feature with a Z or W decaying leptonically

~20 k events produced!



- Top Associated Production :

known at NLO TH uncertainty ~O(15%)

Quite distinctive but also quite crowded

~3 k events produced!

slide courtesy of M. Kado, CERN ATC '14

(SM) Higgs Searches @ the LHC

- Dominant decay mode b (57%)

Very large backgrounds, associated production W,Z H and Boost!

- The ττ channel (6.3%)

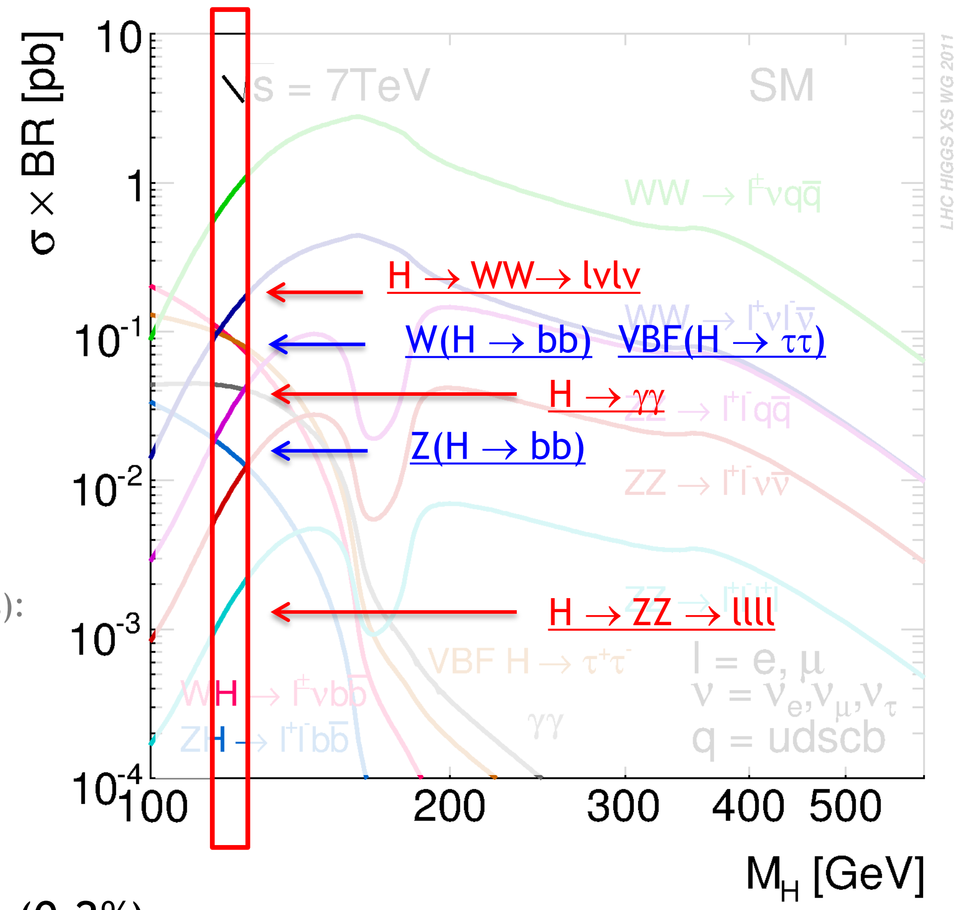
VBF, VH, but also ggF with new mass reconstruction techniques

- The γγ channel (0.2%)

Discovery channel, high mass resolution (High stat, and backgrounds)

- The ZZ Channel (3%)
  - Subsequent all leptons decays (low statistics): golden channel
  - llqq and llvv sensitive mostly at high mass

- The WW Channel (22%)
  - Subsequent lvlv very sensitive channel
  - lvqq sensitive mostly at high mass



- The μμ channel (0.02%) and Zγ (0.2%)

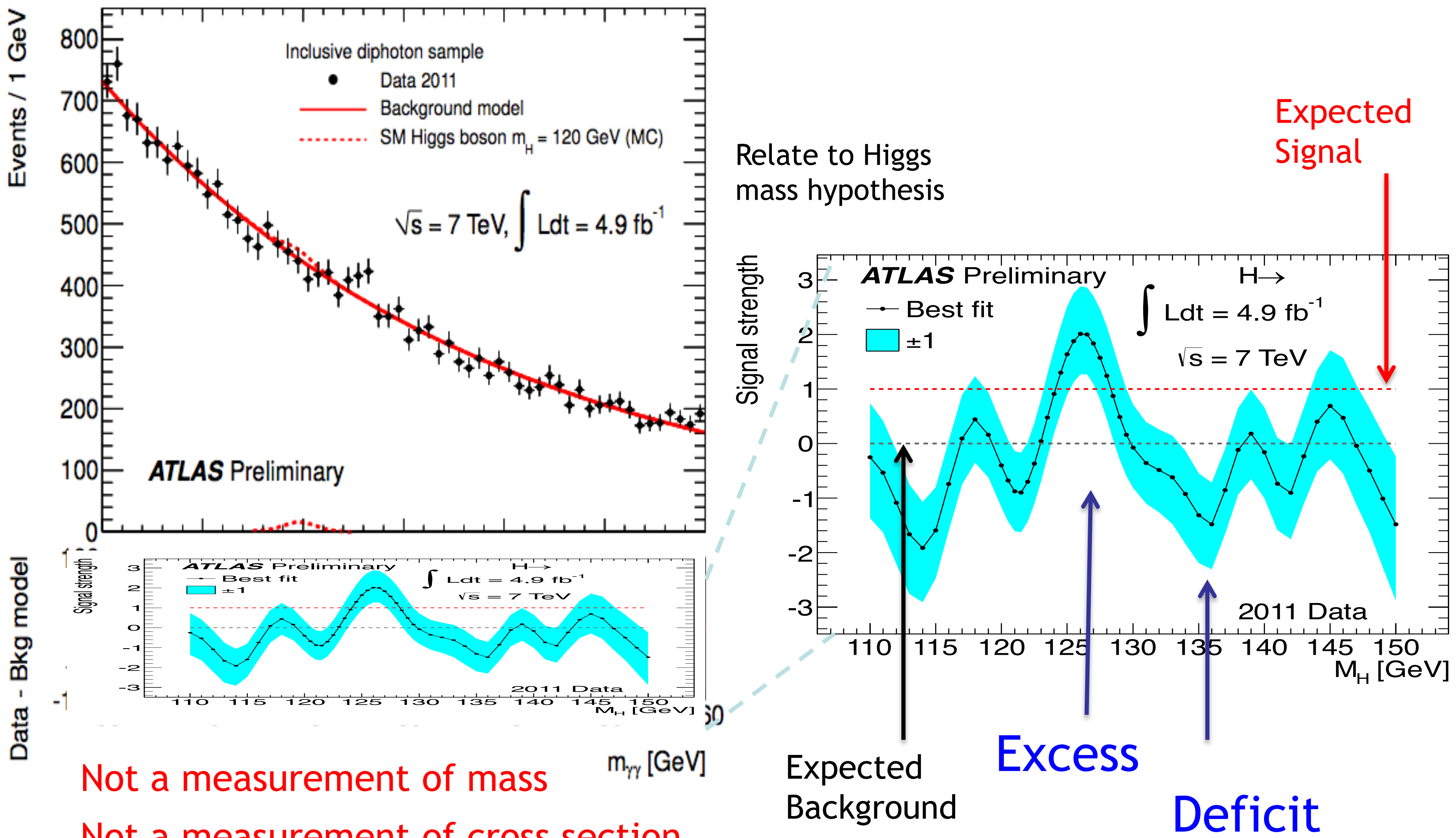
Low statistics from the low branching in μμ or both the low branching and subsequent decay in leptons (Zγ)

- The cc channel (3%) Very difficult

slide courtesy of M. Kado, CERN ATC '14

The Higgs discovery @ the LHC

$$gg \to H \to \gamma\gamma$$



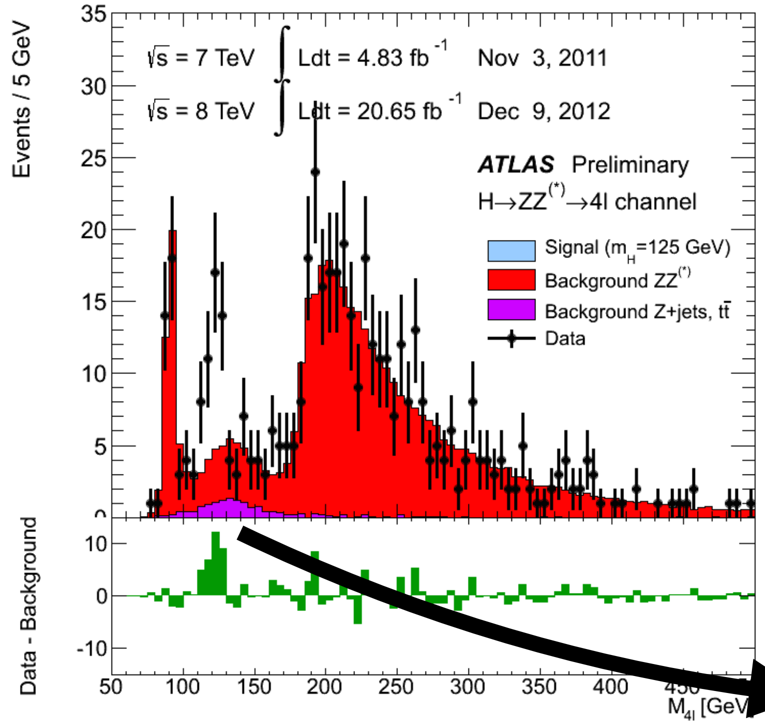
Not a measurement of mass

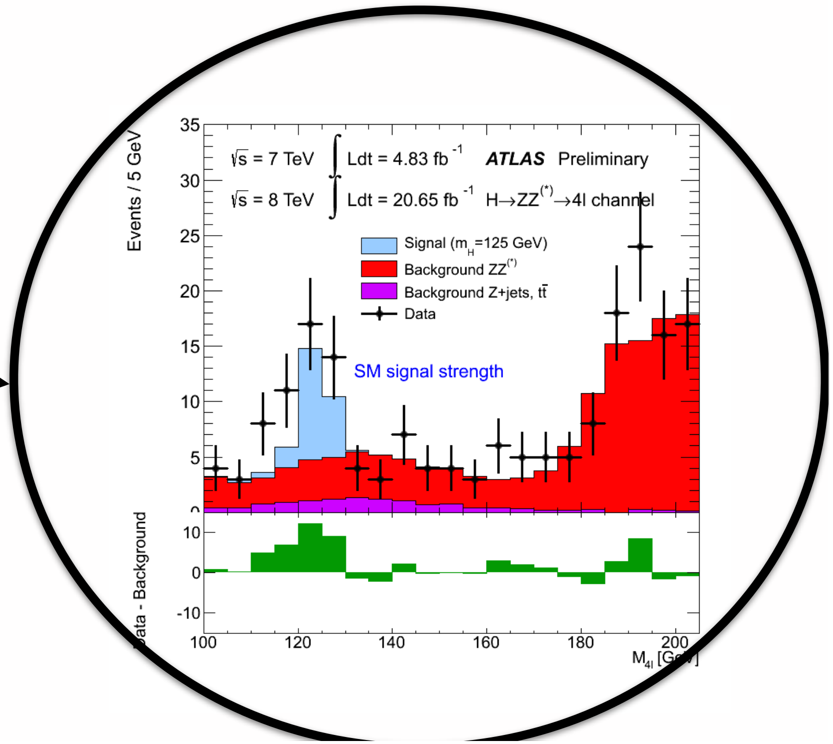
Not a measurement of cross section

slide courtesy of M. Kado, CERN ATC '14

The Higgs discovery @ the LHC

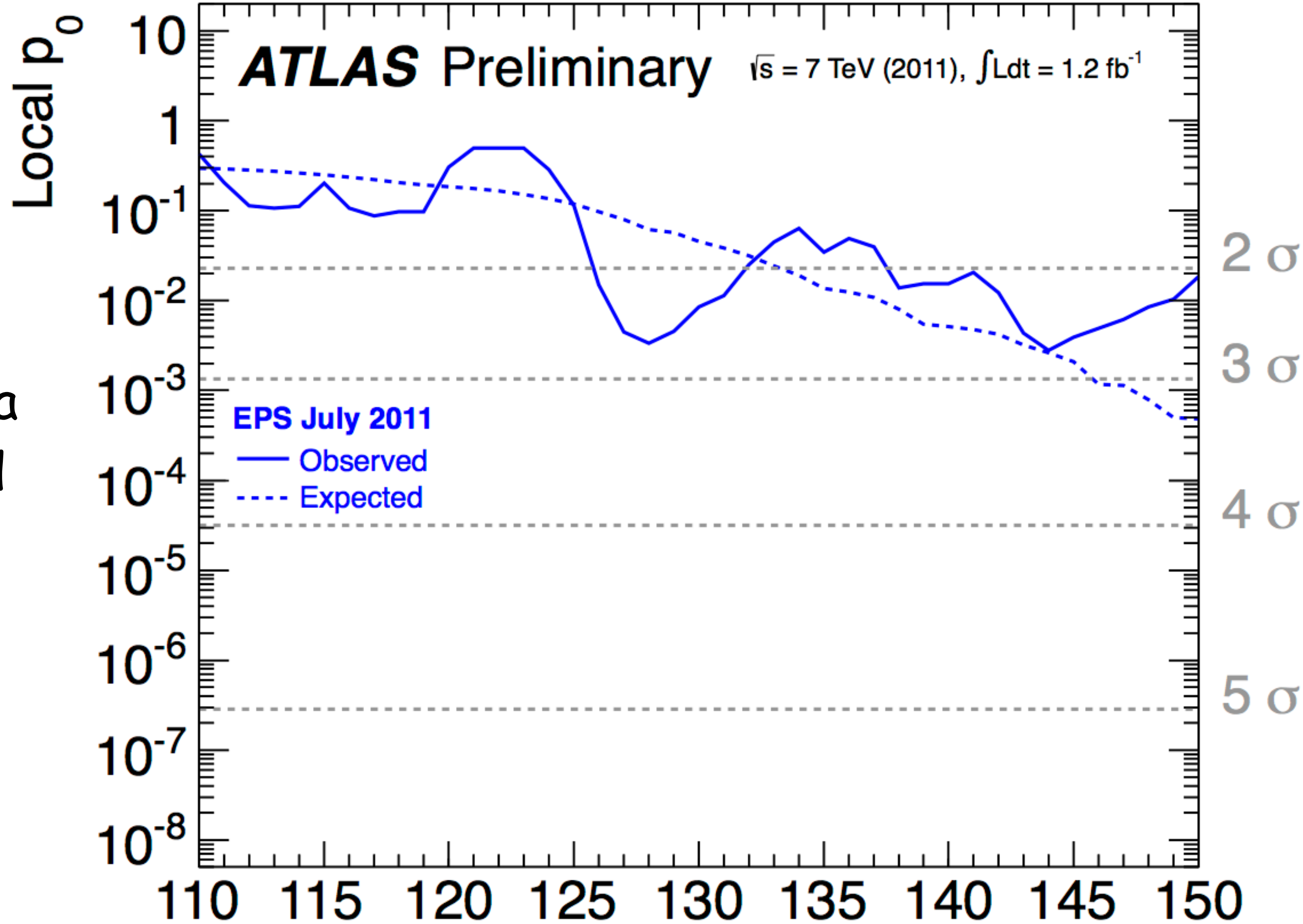
$$gg \to H \to ZZ^* \to 4l$$





Higgs Discovery Reloaded

probability to observe a background fluctuation instead of the signal



Higgs Discovery Reloaded

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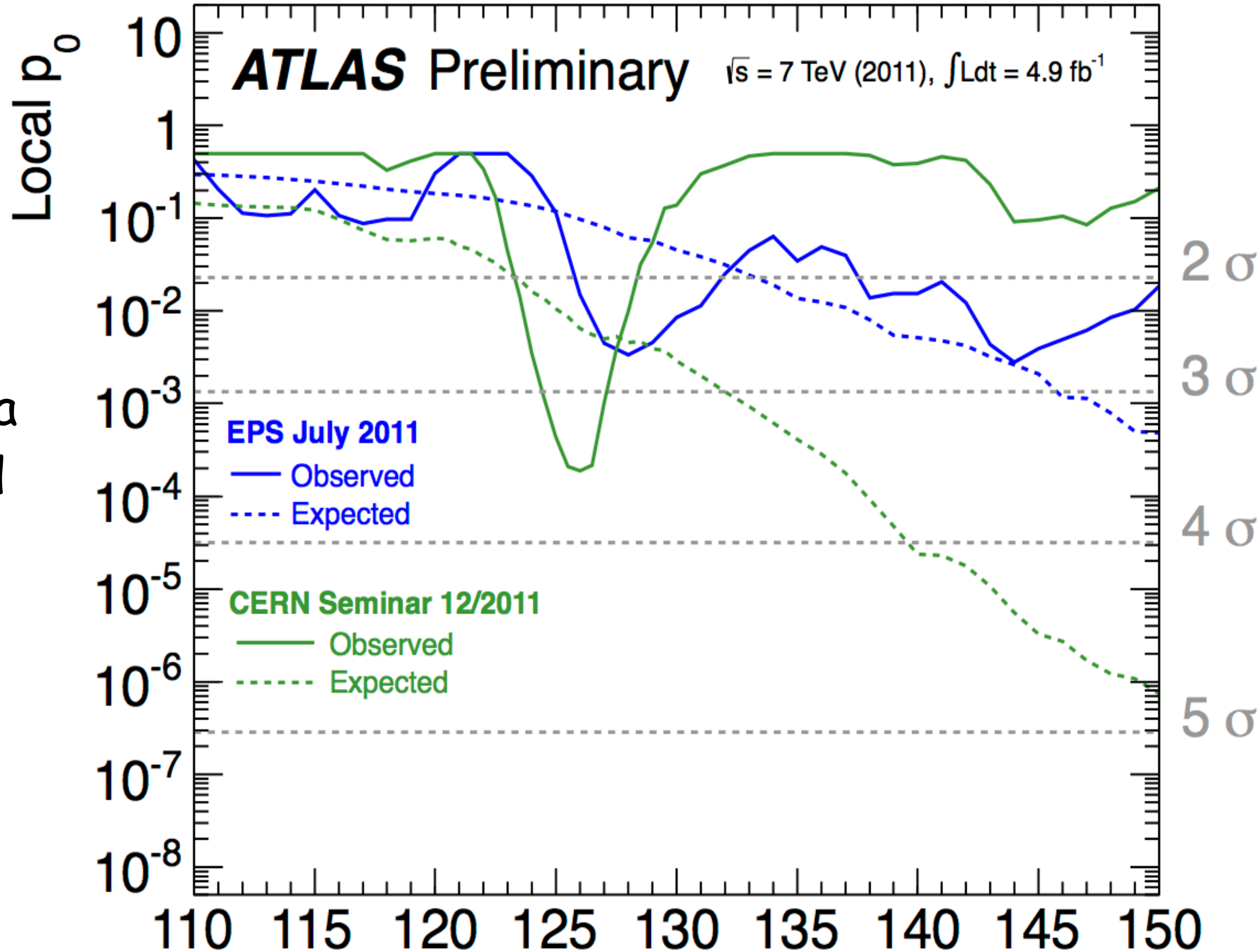
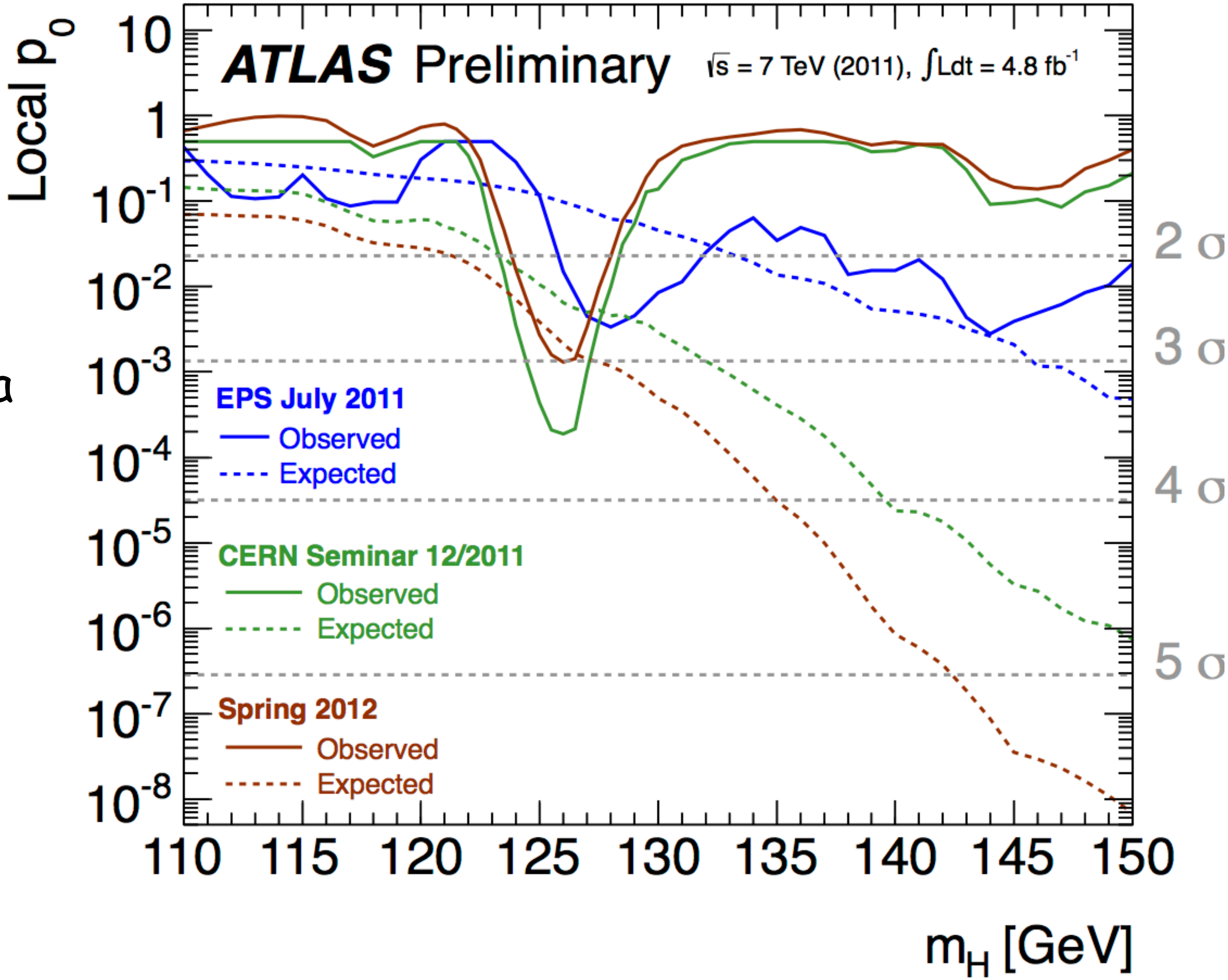


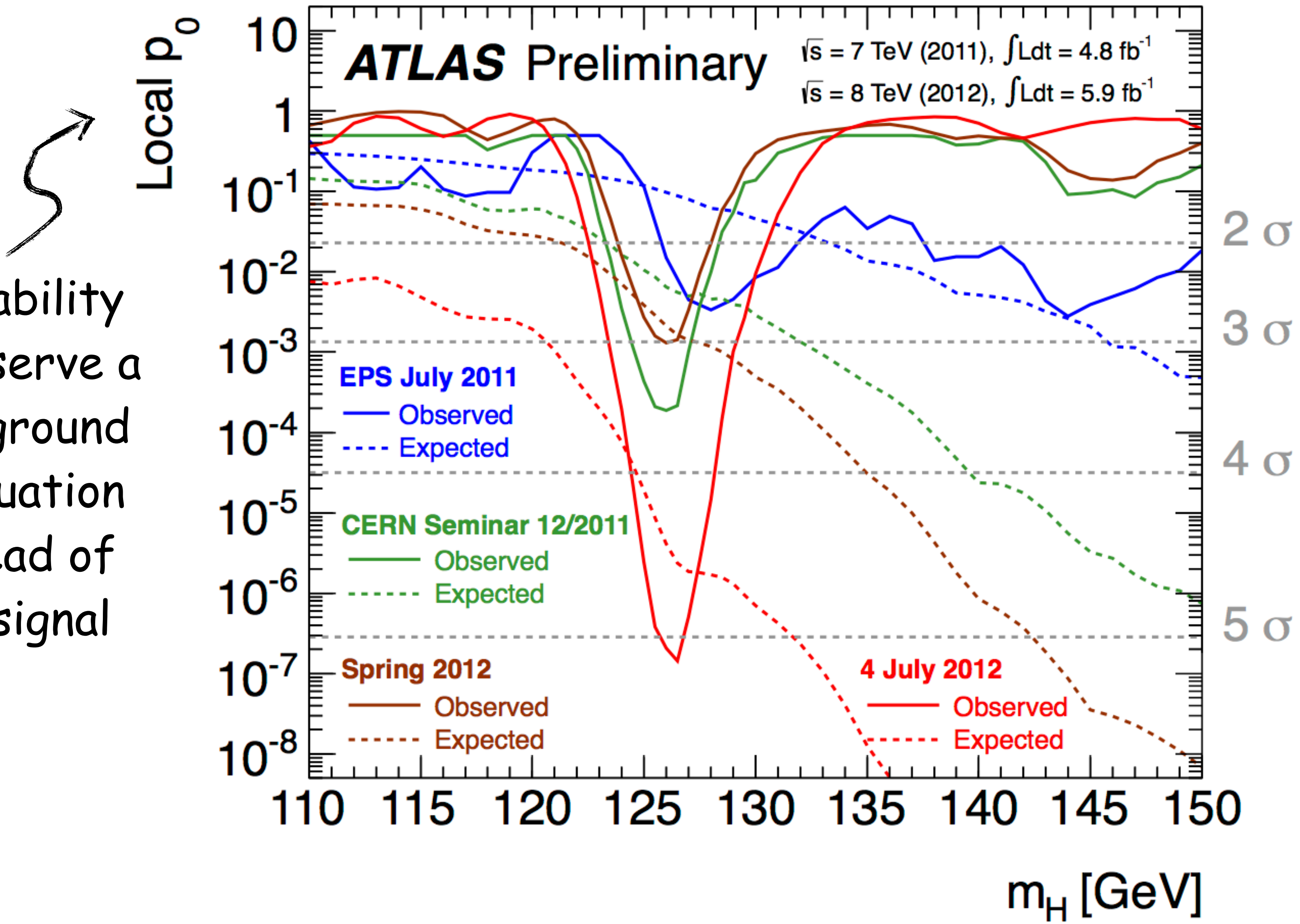
Higgs Discovery Reloaded



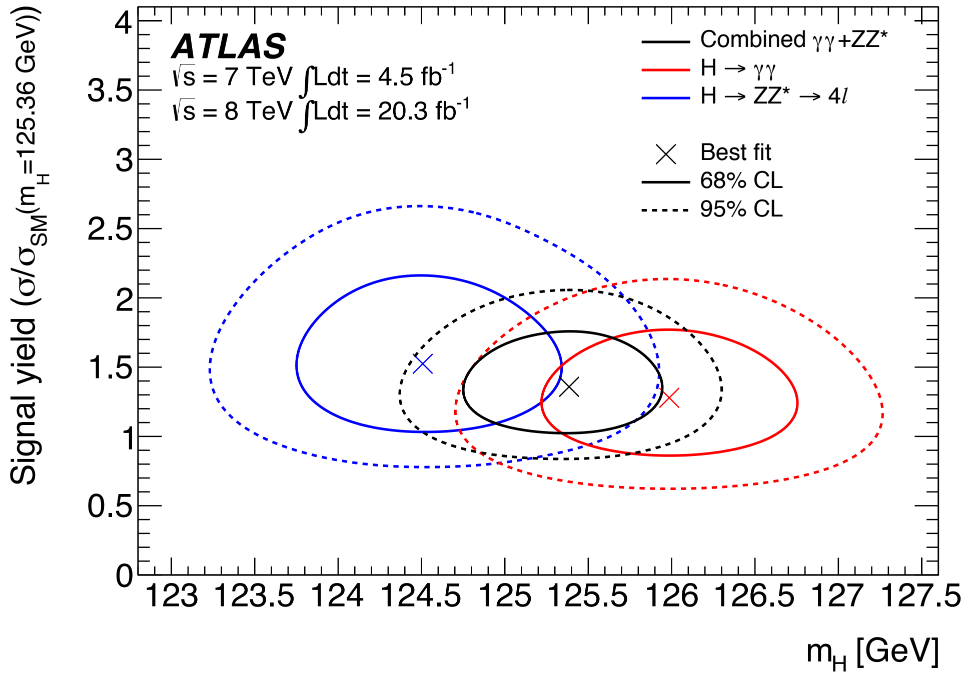
probability to observe a background fluctuation instead of the signal

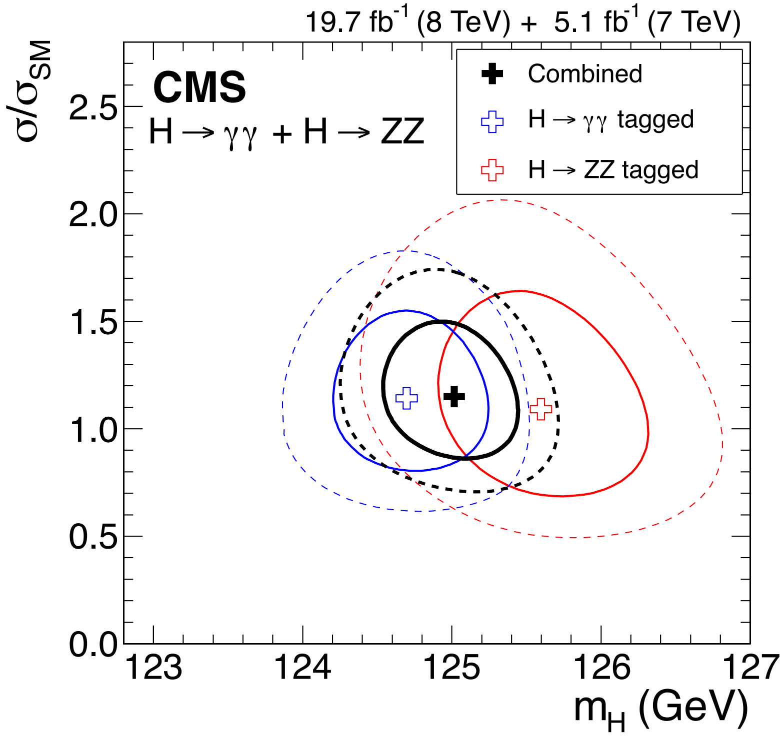
Higgs Discovery Reloaded

probability to observe a background fluctuation instead of the signal



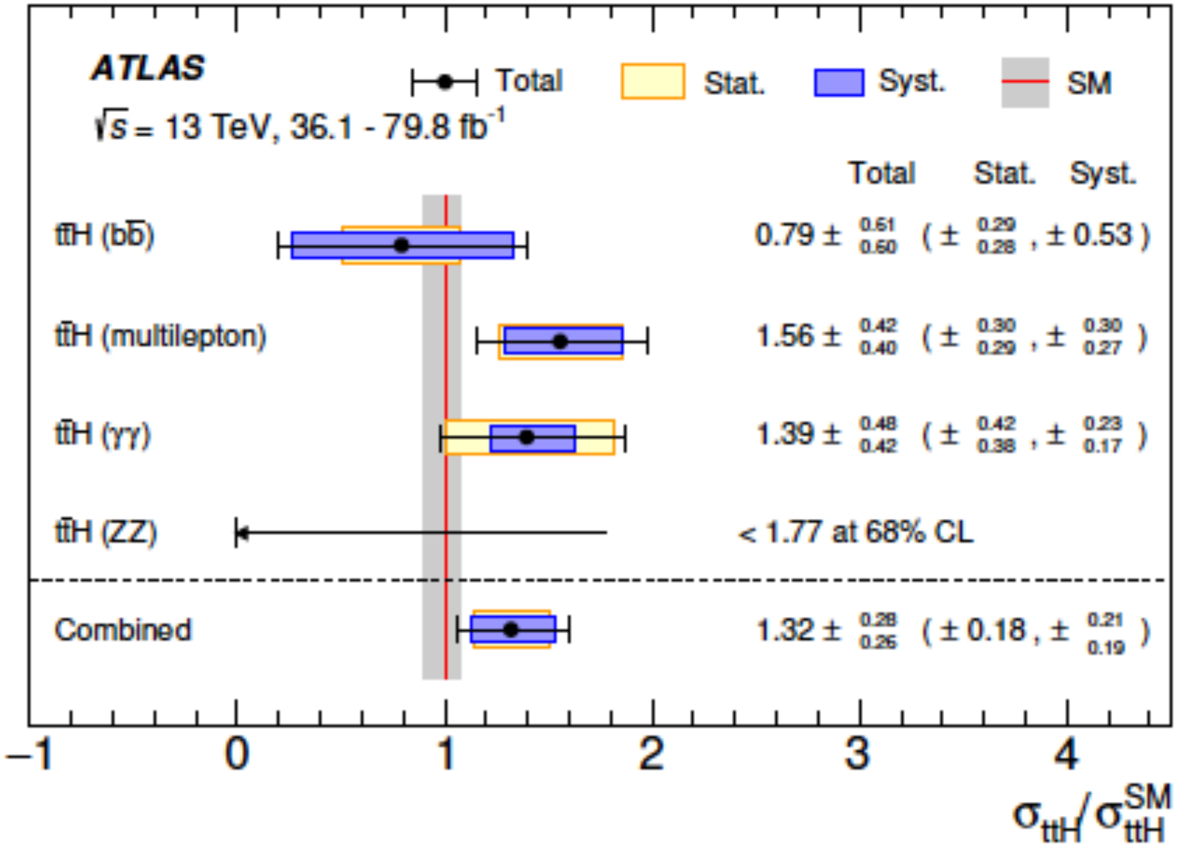
Towards Higgs measurements





Experiment	$H \to \gamma\gamma$	$H \to ZZ^* \to 4\ell$	combined
ATLAS	125.98±0.42(stat.)±0.28(syst.)	124.51±0.52(stat.)±0.06 (syst.)	125.36±0.37(stat.)±0.18 (syst.)
CMS	124.70±0.31(stat.)±0.15(syst.)	125.59±0.42(stat.)±0.17(syst.)	125.02±0.27(stat.)±0.15(syst.)

Higgs physics: still very active topic



Very challenging measurement. Direct evidence of top-Higgs coupling
(but doesn't yet change the global picture)

The Higgs program

" With great power comes great responsibility "

Voltaire & Spider-Man

which, in particle physics, really means

" With great discoveries come great measurements "

BSMers desperately looking for anomalies

(true credit: F. Maltoni)

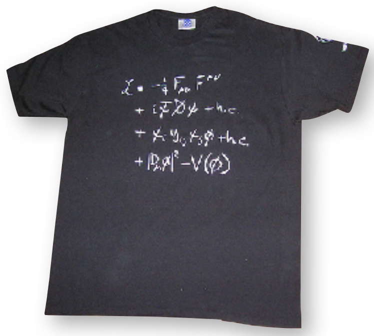
The Higgs has access to EW coupled New Physics
which is less constrained by direct searches than strongly coupled NP

1 Higgs properties

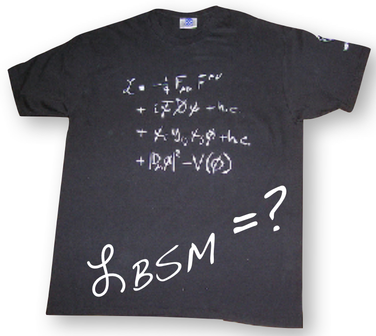
J^{PC}

Important & nice to see progresses but "this question carries a similar potential for surprise as a football game between Brazil and Tonga" Resonaances

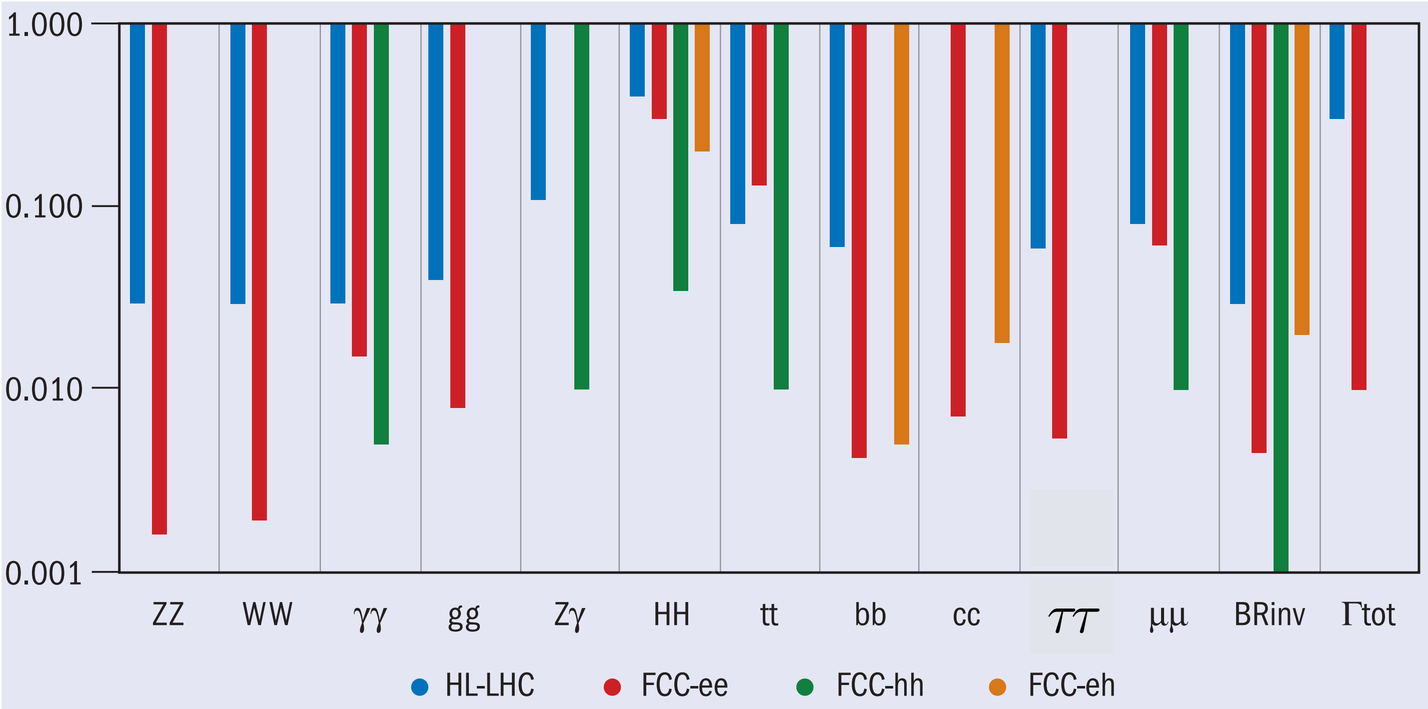
2 Higgs couplings



3 BSM implications



How to report Higgs data: from κ to EFT



Oversimplified PR plot

1) not a unique coupling to each particle

2) powerful complementarity/synergy with non-Higgs measurements not visible (e.g. EW, diboson, top)

How to report Higgs data: from κ to EFT

LHCHXSWG '12

M. Zuckerberg created FaceMash before Facebook

J.K. Rowling got rejected 12 times by editors before she published Harry Potter

Beyonce wrote hundreds of songs before 'Halo'

... Physicists used signal strengths to report Higgs data before ...

one doesn't have to succeed on the first try

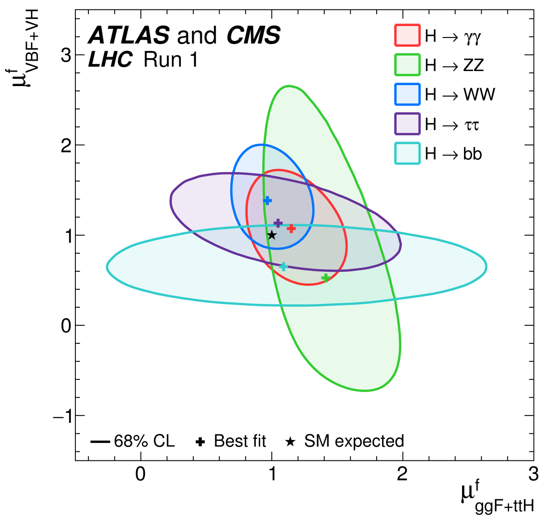
"the success comes from the freedom to fail"

M. Zuckerberg, Harvard graduation ceremony speech, May 25, 2017

How to report Higgs data: from κ to EFT

LHCHXSWG '12

$$\mu_i = \frac{\sigma[i \to h]}{(\sigma[i \to h])_{\text{SM}}} \qquad \mu_f = \frac{\text{BR}[h \to f]}{(\text{BR}[h \to f])_{\text{SM}}}$$



How to report Higgs data: from κ to EFT

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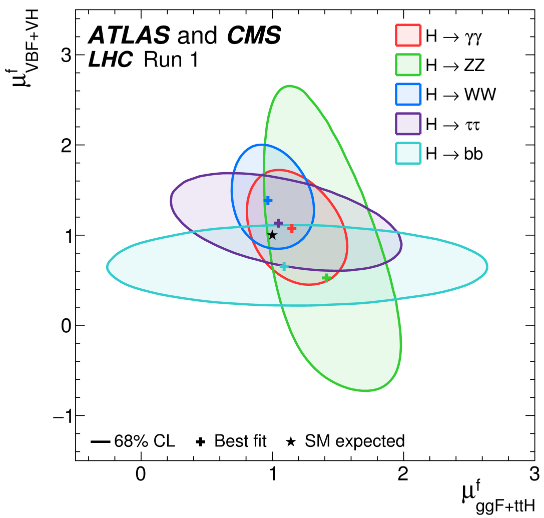

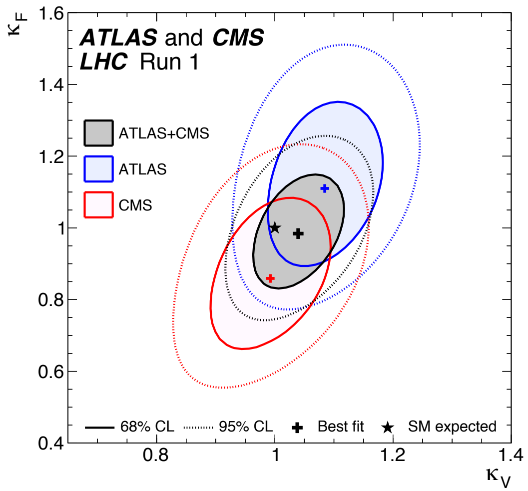

$$(\sigma \cdot {\rm BR})\,(gg \to H \to \gamma\gamma) \;=\; \sigma_{\rm SM}(gg \to H) \cdot {\rm BR}_{\rm SM}(H \to \gamma\gamma) \cdot \frac{\kappa_g^2 \cdot \kappa_\gamma^2}{\kappa_H^2}$$

individual coupling rescaling factors

How to report Higgs data: from κ to EFT

LHCHXSWG '12

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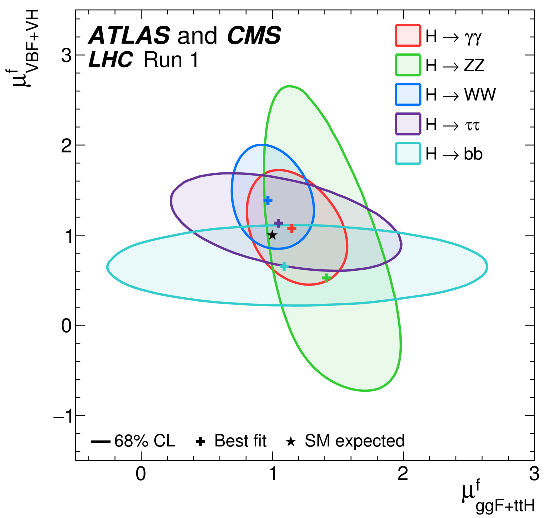

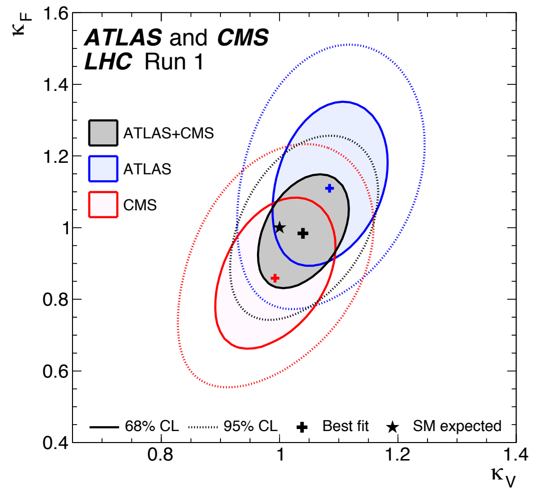

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individual coupling rescaling factors

Well suited parametrization for inclusive measurements
but doesn't do justice to full possible SM deformations & rich diff. information

How to report Higgs data: from κ to EFT

LHCHXSWG '12

Main drawbacks of μ and κ

1) No SU(2)xU(1) gauge invariant formalism

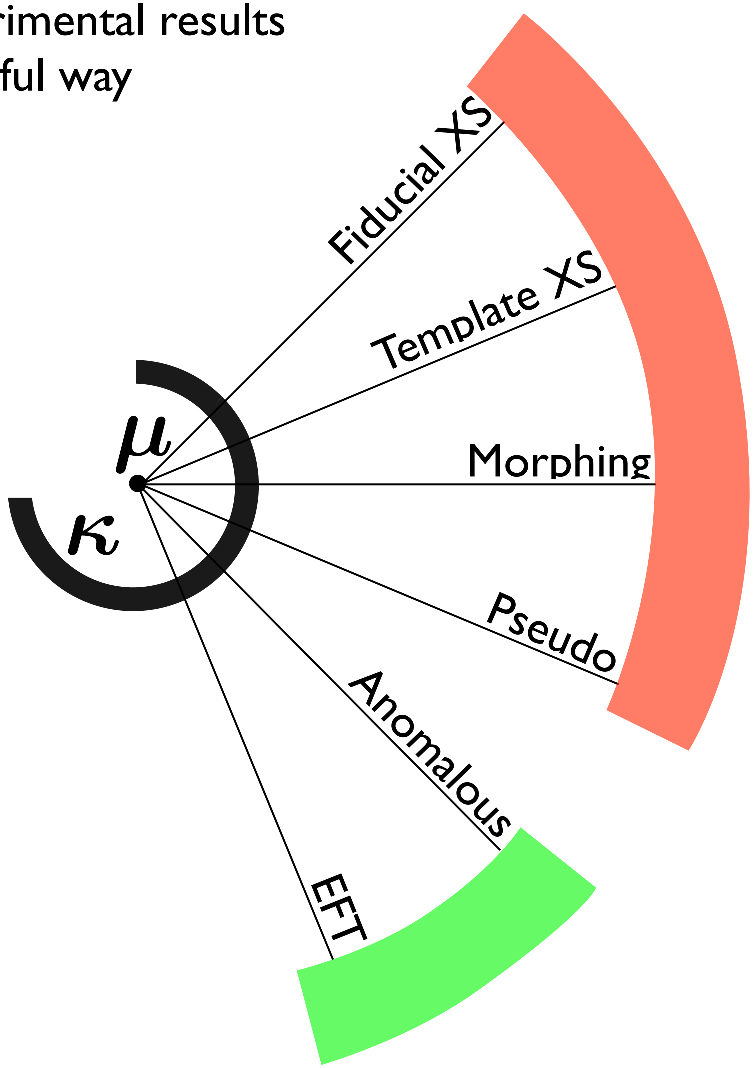
2) Missing some important symmetry properties of SM, already well constrained e.g. in EW precision measurements

3) very difficult to go beyond LO

Well suited parametrization for inclusive measurements
but doesn't do justice to full possible SM deformations & rich diff. information

Not unique!
Useful tools to probe
broad classes of dynamics
and to report experimental results
in a meaningful way

EFT



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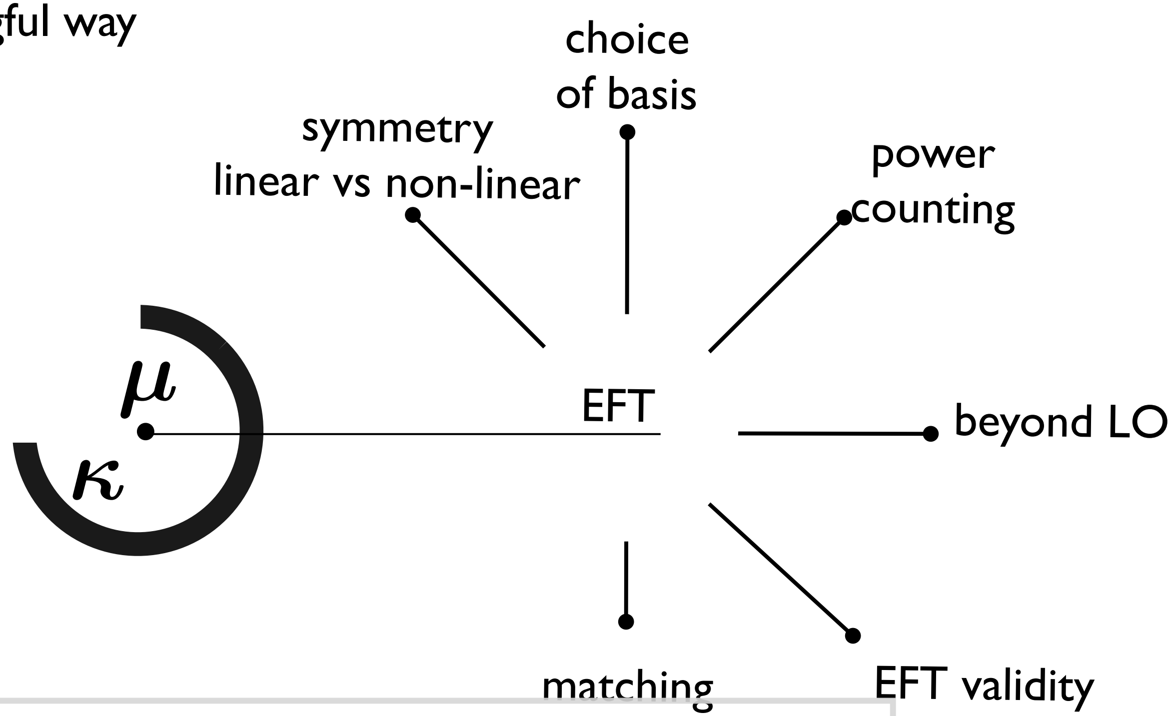


Pros:

- correlations between different channels/observables
- combination of measurements at different energies
  e.g. EW precision data and Higgs measurements
- test of self-consistency

unique to EFT

⇒ allow to focus on channels yet unconstrained and more likely to offer new discovery opportunities

κ vs EFT

	ILC250		+ILC500	
	κ fit	EFT fit	κ fit	EFT fit
$g(hbb)$	1.8	1.1	0.60	0.58
$g(hcc)$	2.4	1.9	1.2	1.2
$g(hgg)$	2.2	1.7	0.97	0.95
$g(hWW)$	1.8	0.67	0.40	0.34
$g(h\tau\tau)$	1.9	1.2	0.80	0.74
$g(hZZ)$	0.38	0.68	0.30	0.35
$g(h\gamma\gamma)$	1.1	1.2	1.0	1.0
$g(h\mu\mu)$	5.6	5.6	5.1	5.1
$g(h\gamma Z)$	16	6.6	16	2.6
$g(hbb)/g(hWW)$	0.88	0.86	0.47	0.46
$g(h\tau\tau)/g(hWW)$	1.0	1.0	0.65	0.65
$g(hWW)/g(hZZ)$	1.7	0.07	0.26	0.05
Γ_h	3.9	2.5	1.7	1.6
$BR(h \to inv)$	0.32	0.32	0.29	0.29
$BR(h \to other)$	1.6	1.6	1.3	1.2

LCC Physics WG,
1710.07621

EFT is doing much better than κ for 250 GeV

BECAUSE

EFT automatically implements correlations that follow from gauge invariance

EFT@dim-6 level has custodial symmetry built-in

Such a difference is less striking at higher energies because direct access to VBF and hWW coupling

Higgs physics vs BSM

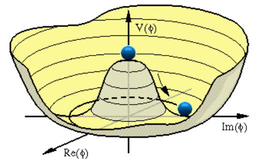
(courtesy of A. Pomarol@Moriond2014)

Several deformations
away from the SM
affecting Higgs properties
are already probed in the vacuum

(assuming EW symmetry linearly realized
and that new physics is heavy)

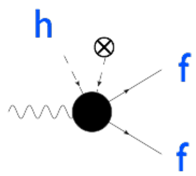
$\phi = v + h$

↪ vacuum

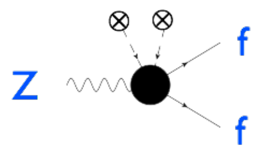


Potentially new BSM-effects in h physics
could have been already tested in the vacuum

e.g.



$= \frac{1}{2v} \times$



$H^\dagger D_\mu H \bar{f} \gamma^\mu f$

(assuming that the Higgs boson is part of a doublet)

Modifications in h→Zff related to Z→ff

consistency check
not discovery mode

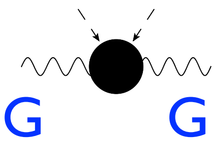
One can use h→ZZ→4l to probe this deformation
but hard time to compete with LEP bounds

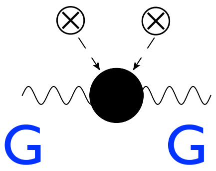
Higgs/BSM Primaries

There are others deformations away from the SM
that are harmless in the vacuum
and need a Higgs field to be probed

(courtesy of A. Pomarol@HiggsHunting2014)

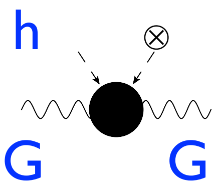
e.g. $$\frac{1}{g_s^2}G_{\mu\nu}^2 + \frac{|H|^2}{\Lambda^2}G_{\mu\nu}^2 \to \left(\frac{1}{g_s^2} + \frac{v^2}{\Lambda^2}\right) G_{\mu\nu}^2$$





operator
not visible in the vacuum
(redefinition of input parameter)

But can affect h physics:



affects GG →h!

operator
visible in Higgs physics

this BSM operator is visible only in Higgs physics!

Higgs/BSM Primaries

Pomarol, Riva '13
Elias-Miro et al '13
Gupta, Pomarol, Riva '14

How many of these effects can we have?

As many as parameters in the SM: **8** for one family *(assuming CP-conservation)*

g_s	$\lvert H\rvert^2 G^A_{\mu\nu} G^{A\mu\nu}$	→	GGh coupling
g	$\lvert H\rvert^2 B_{\mu\nu} B^{\mu\nu}$	→	hγγ coupling
g'	$\lvert H\rvert^2 W^a_{\mu\nu} W^{\mu\nu\, a}$	→	hZγ coupling
m_W	$\lvert H\rvert^2 \lvert D_\mu H\rvert^2$	→	hVV* (custodial invariant)
m_h	$\lvert H\rvert^6$	→	h^3 coupling
m_f (f=t,b,τ)	$\lvert H\rvert^2 \bar{f}_L H f_R + h.c.$	→	htt, hbb, h$\tau\tau$

yet to be measured at the LHC (hZγ coupling, h^3 coupling)

the 6 others have been measured (~15%)

Higgs/BSM Primaries

Pomarol, Riva '13
Elias-Miro et al '13
Gupta, Pomarol, Riva '14

Almost a 1-to-1 correspondence

Coupling	300 fb^{-1} Theory unc.: All	Half	None	3000 fb^{-1} Theory unc.: All	Half	None
κ_Z	8.1%	7.9%	7.9%	4.4%	4.0%	3.8%
κ_W	9.0%	8.7%	8.6%	5.1%	4.5%	4.2%
κ_t	22%	21%	20%	11%	8.5%	7.6%
κ_b	23%	22%	22%	12%	11%	10%
κ_τ	14%	14%	13%	9.7%	9.0%	8.8%
κ_μ	21%	21%	21%	7.5%	7.2%	7.1%
κ_g	14%	12%	11%	9.1%	6.5%	5.3%
κ_γ	9.3%	9.0%	8.9%	4.9%	4.3%	4.1%
$\kappa_{Z\gamma}$	24%	24%	24%	14%	14%	14%

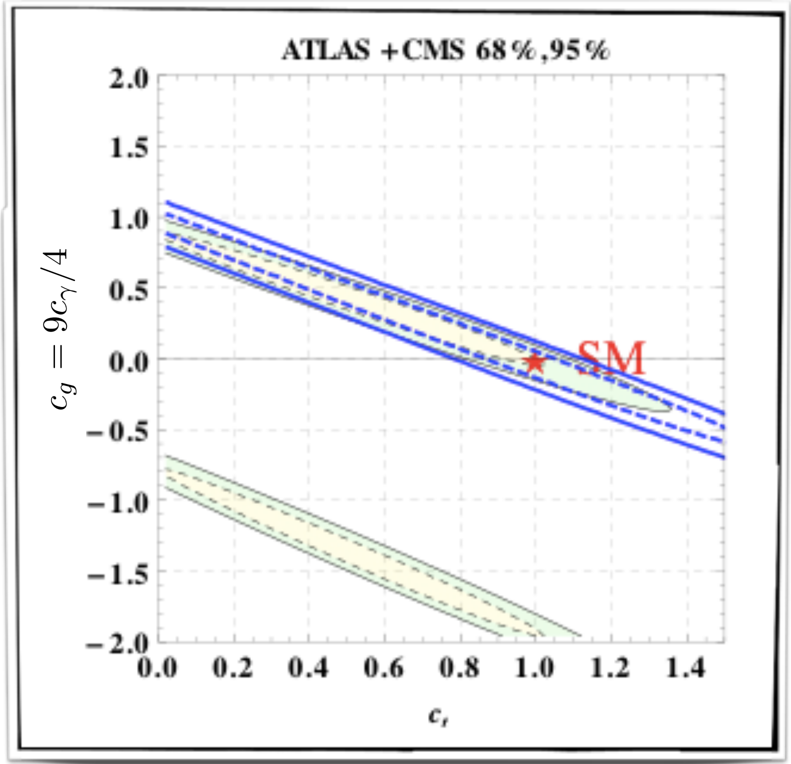
Atlas projection

With some important differences

1) width hypothesis built-in

2) κ_W/κ_Z is not a primary (constrained by $\Delta\rho$ and TGC)

3) κ_g, κ_γ, $\kappa_{Z\gamma}$ do not separate UV and IR contributions



Azatov '15

the 6 others have been measured (~15%)

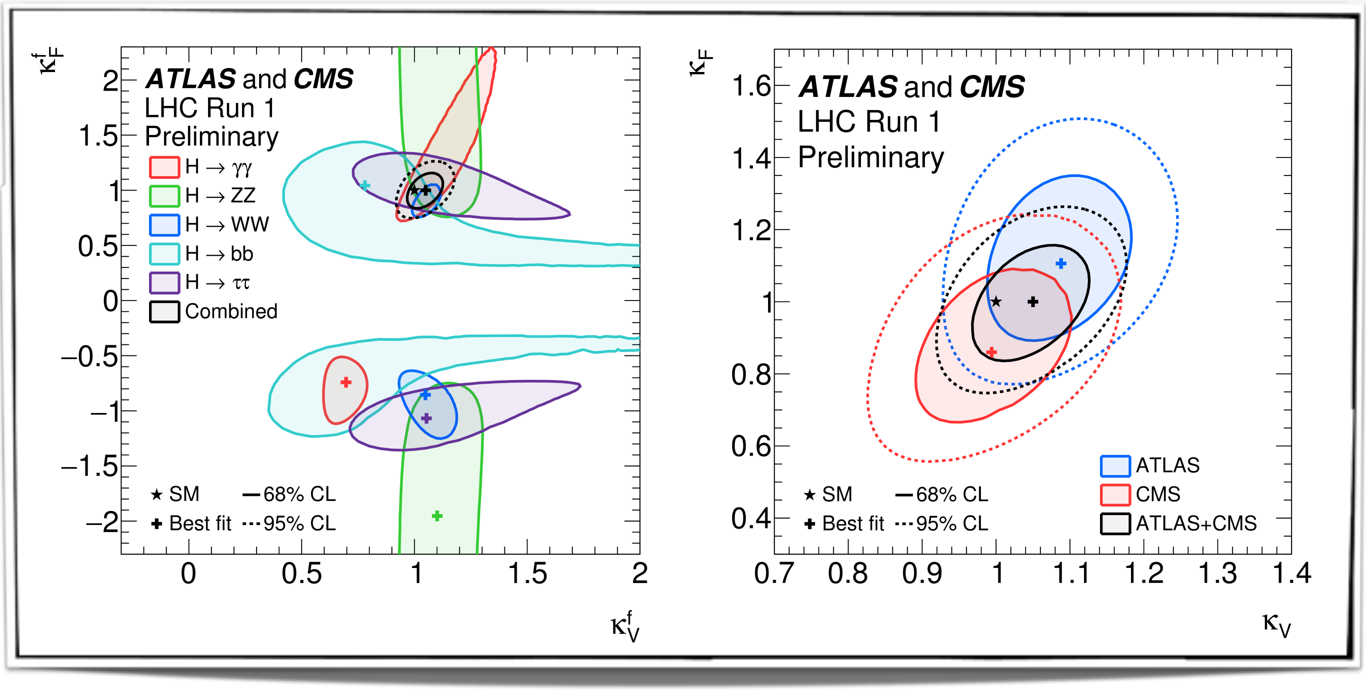
up to a flat direction between between the top/gluon/photon couplings

Why going beyond inclusive Higgs processes?

So far the LHC has mostly produced Higgses on-shell in processes with a characteristic scale $\mu \approx m_H$

⇩ ⇩

access to Higgs couplings @ m_H



Why going beyond inclusive Higgs processes?

So far the LHC has mostly produced Higgses on-shell
in processes with a characteristic scale $\mu \approx m_H$

⇩ ⇩

access to Higgs couplings @ m_H

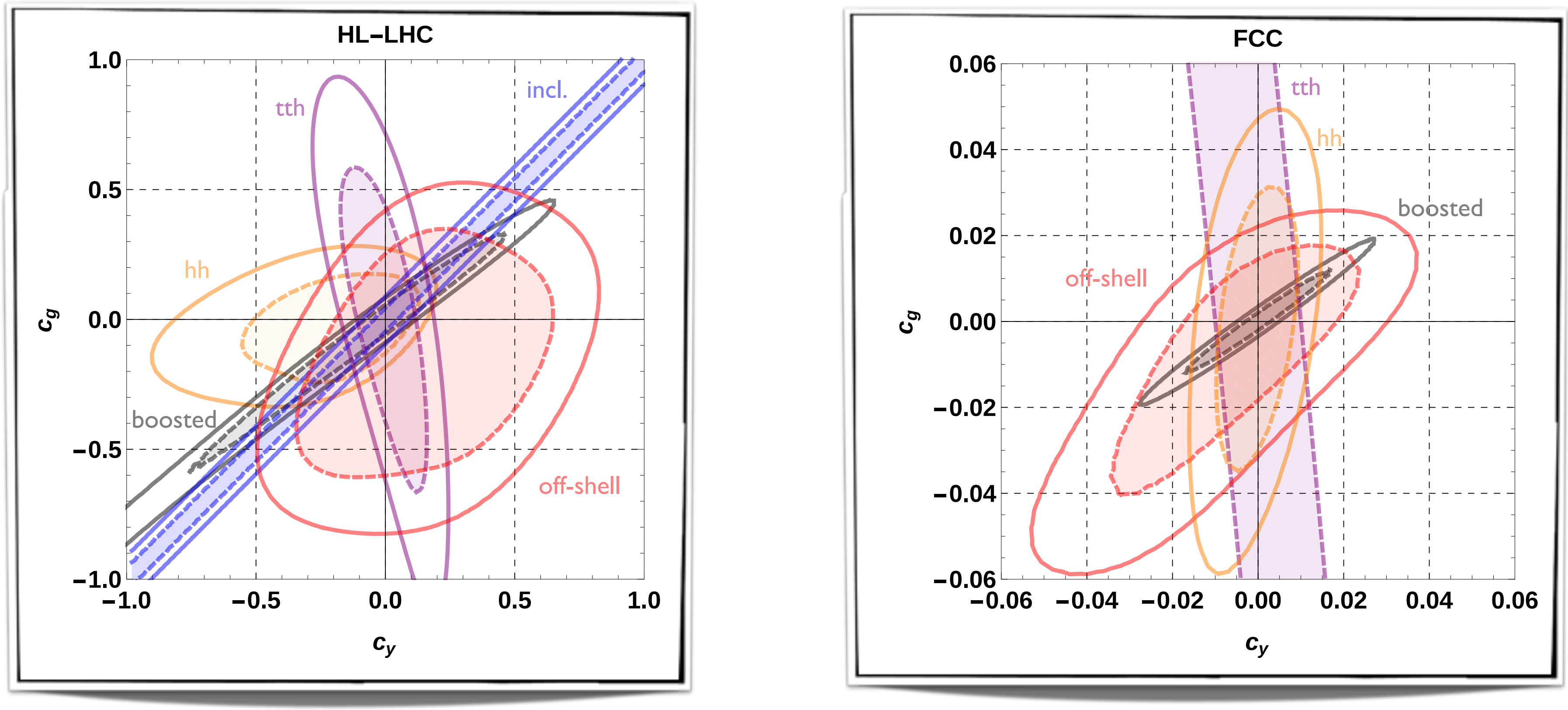
Producing a Higgs with boosted additional particle(s)
probe the Higgs couplings @ large energy
(important to check that the Higgs boson ensures perturbative unitarity)

Examples of interesting channels to explore further:

1. off-shell $gg \to h^* \to ZZ \to 4l$
2. boosted Higgs: Higgs+ high-p_T jet
3. double Higgs production

Why going beyond inclusive Higgs processes?

So far the LHC has mostly produced Higgses on-shell
in processes with a characteristic scale μ ≈ m_H

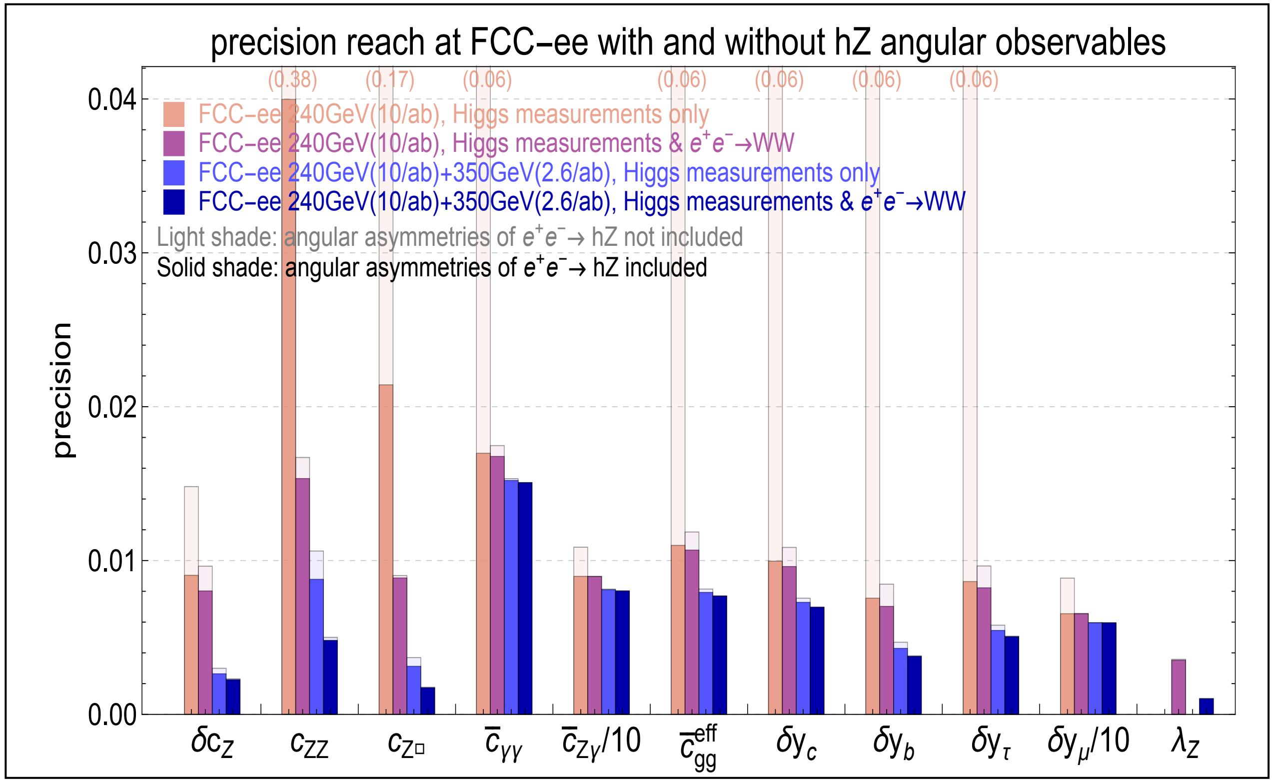


Azatov, Grojean, Paul, Salvioni '16

Why going beyond inclusive Higgs processes?

Can access ‘derivative’ operators at ee colliders by using angular observables

Durieux, Grojean, Gu, Wang ’17

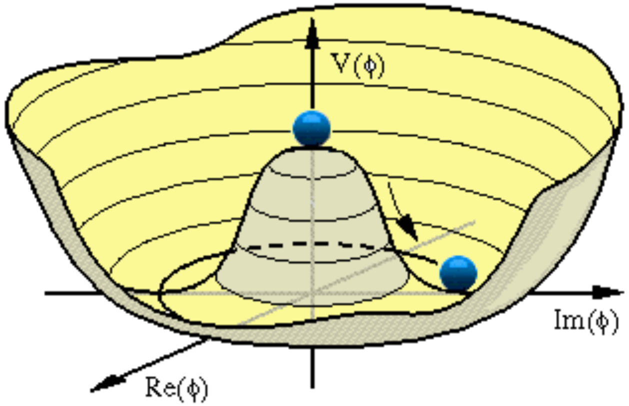


1) with a run at 240/250 GeV alone, crucial to have access to angular distributions to break degeneracies

2) with a second run at higher energy makes it less important to look at distributions

Quantum corrections to the Higgs potential

Higgs and EW vacuum Stability

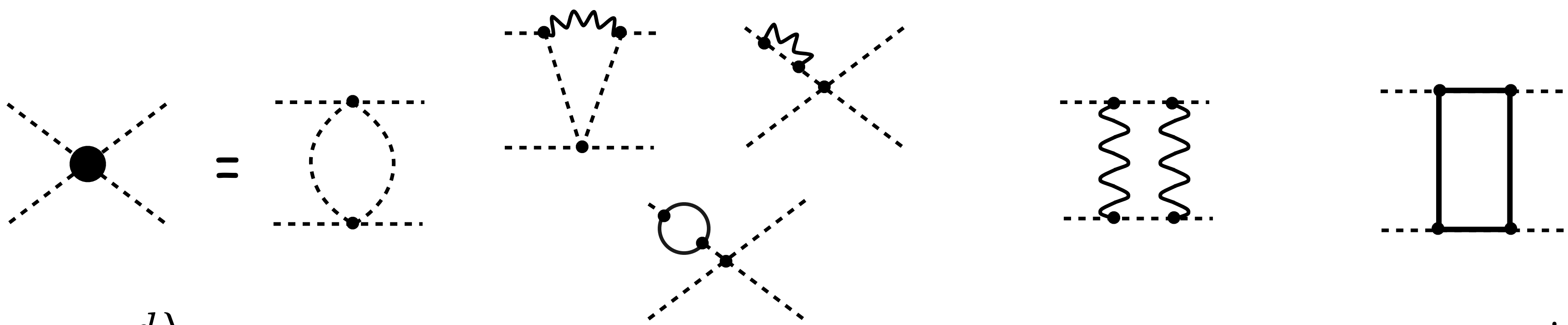


$$V(h) = -\tfrac{1}{2}\mu^2 h^2 + \tfrac{1}{4}\lambda h^4$$

vev: $v^2 = \mu^2/\lambda$ mass: $m_H^2 = 2\lambda v^2$

the vacuum is not empty even classically $(\hbar \to 0)$

How is Quantum Mechanics changing the picture?



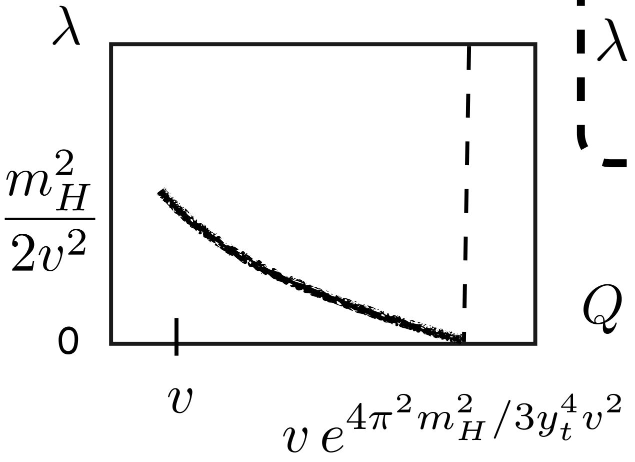
$$16\pi^2 \frac{d\lambda}{d\ln Q} = 24\lambda^2 - (3g'^2 + 9g^2 - 12y_t^2)\lambda + \tfrac{3}{8}g'^4 + \tfrac{3}{4}g'^2 g^2 + \tfrac{9}{8}g^4 - 6y_t^4 +$$ Higher loops Small Yukawa

Higgs and EW vacuum Stability

Small mass (y_t dominated RGE)

$$\lambda(Q) = \lambda_0 - \frac{\frac{3}{8\pi^2} y_0^4 \ln \frac{Q}{Q_0}}{1 - \frac{9}{16\pi^2} y_0^2 \ln \frac{Q}{Q_0}}$$

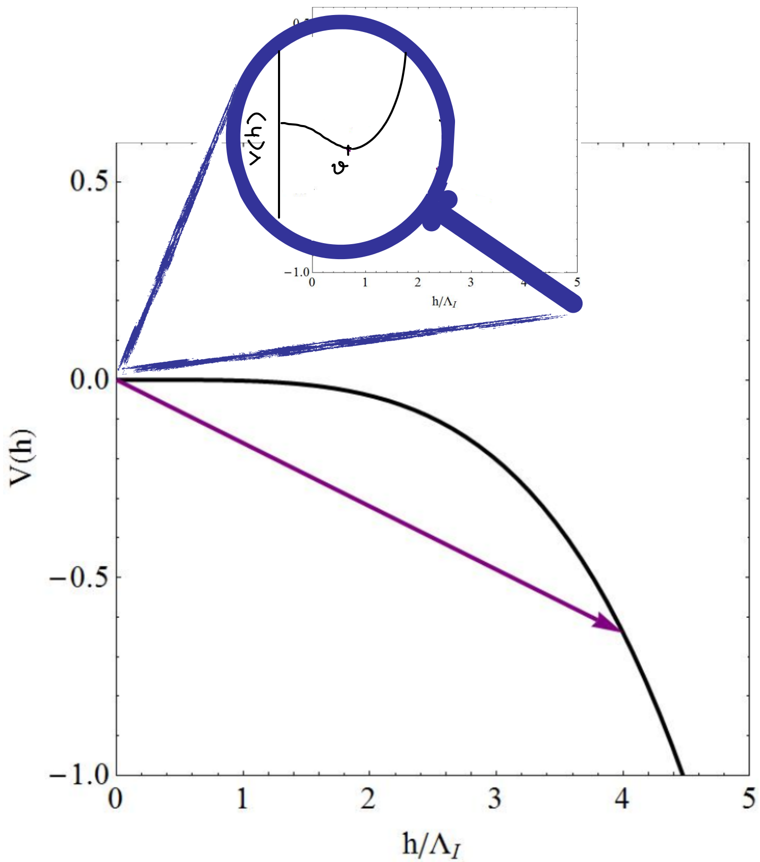
Linde '76, '80
Weinberg '76
Maini et al '78, '79
Politzer, Wolfram '79
Lindner '86
+...



$\lambda < 0$ ⇛ potential unbounded from below

$$\Lambda \leq v\, e^{4\pi^2 m_H^2/3y_t^4 v^2}$$

New physics should appear before that point to restore stability



Higgs and EW vacuum Stability

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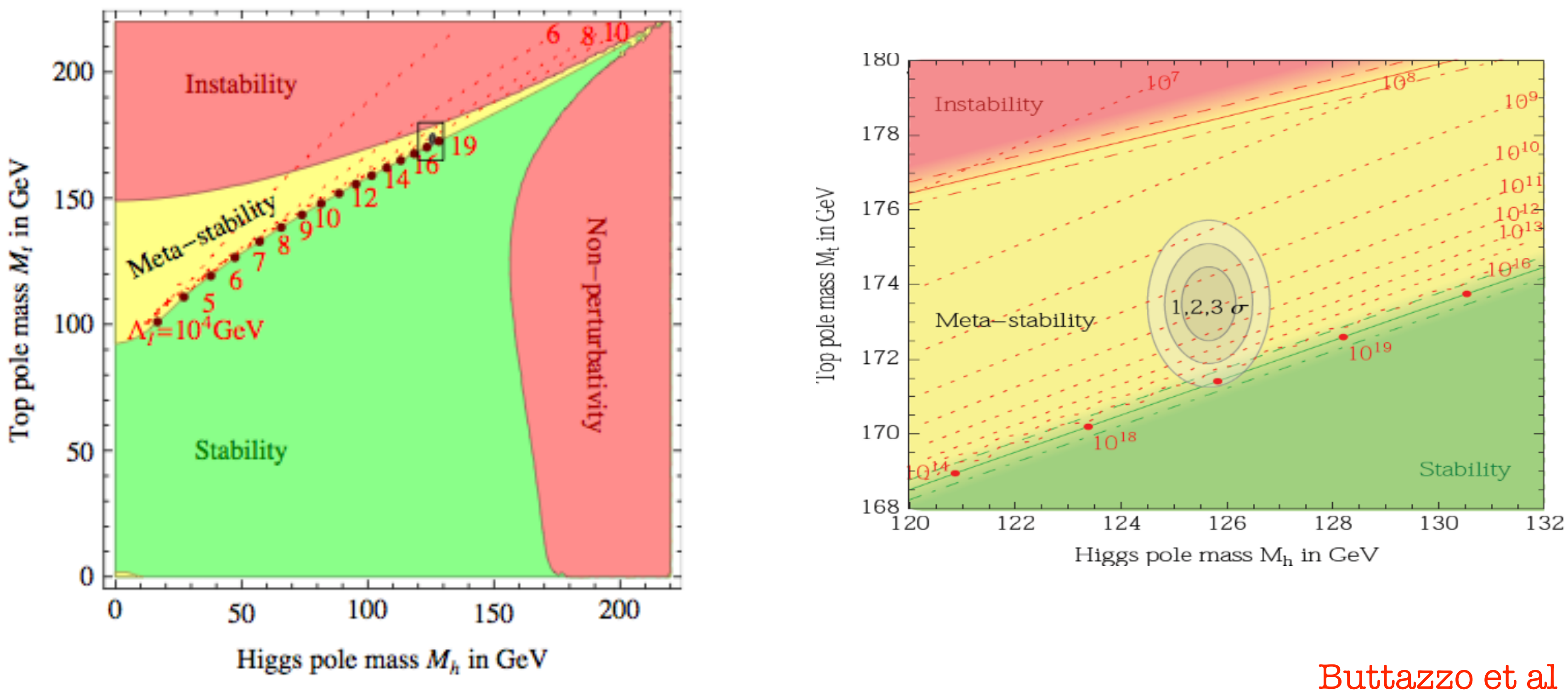
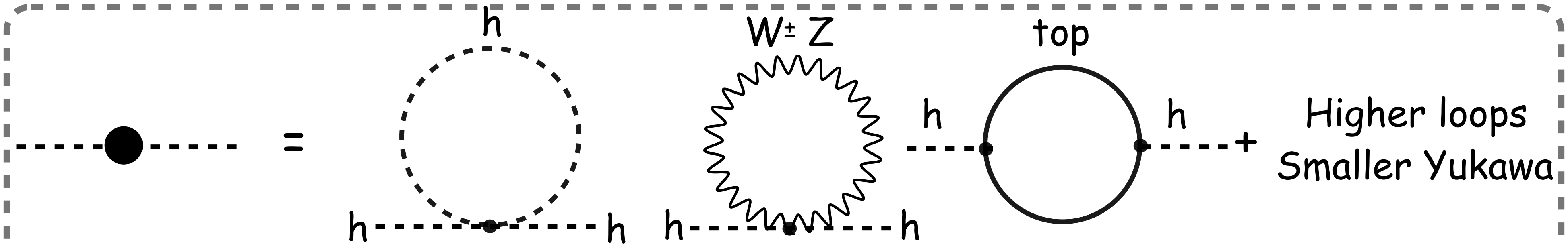


Buttazzo et al '13

Quantum Instability of the Higgs Mass

so far we looked only at the RG evolution of the Higgs quartic coupling (dimensionless parameter). The Higgs mass has a totally different behavior: it is highly dependent on the UV physics, which leads to the so called hierarchy problem



$$\int \frac{d^4k}{(2\pi)^4} \frac{1}{k^2 - m^2} \propto \Lambda^2 \qquad \int \frac{d^4k}{(2\pi)^4} \frac{k^2}{(k^2 - m^2)^2} \propto \Lambda^2$$

Weisskopf '39
't hooft '79

$$\delta m_H^2 = \left(2m_W^2 + m_Z^2 + m_H^2 - 4m_t^2\right) \frac{3G_F\Lambda^2}{8\sqrt{2}\pi^2}$$

$$m_H^2 \sim m_0^2 - (115 \text{ GeV})^2 \left(\frac{\Lambda}{700 \text{ GeV}}\right)^2$$

The hierarchy problem made easy

only a few electrons are enough to lift your hair (~ 10^{25} mass of e^-)

the electric force between 2 e^- is 10^{43} times larger than their gravitational interaction

we don't know why gravity is so weak?

we don't know why the masses of particles are so small?

Several theoretical hypotheses

new dynamics? new symmetries? new space-time structure?

modification of special relativity? of quantum mechanics?

The Higgs hierarchy problem

Naturalness principle @ work

Following the arguments of Wilson, 't Hooft (and others):
only small numbers associated to the breaking of a symmetry survive quantum corrections

Introduce new degrees of freedom to regulate the high-energy behavior

Beautiful examples of naturalness to understand the need of "new" physics

see for instance Giudice '13 (and refs. therein) for an account

- the need of the **positron** to screen the electron self-energy: $\Lambda < m_e/\alpha_{\rm em}$
- the **rho meson** to cutoff the EM contribution to the charged pion mass: $\Lambda < \delta m_\pi^2/\alpha_{\rm em}$
- the kaon mass difference regulated by the **charm** quark: $\Lambda^2 < \frac{\delta m_K}{m_K} \frac{6\pi^2}{G_F^2 f_K^2 \sin^2\theta_C}$
- the light **Higgs** boson to screen the EW corrections to gauge bosons self-energies
- ...
- **new physics** at the weak scale to cancel the UV sensitivity of the Higgs mass?

The different paths to Higgs naturalness

- Single vacuum

the low Higgs mass is screened from large quantum corrections by

1. a symmetry (Susy, PQ)
2. a form factor (composite Higgs)
3. a low UV scale (xdim, RS, large N…)
4. a combination of the above

- Multiple vacua

many metastable vacua
with a vast range of values for m_H
Dynamical (or anthropic selection) of $m_H \ll \Lambda$

1. anthropic multiverse
2. NNaturalness with 10^{16} copies of SM
3. relaxion and cosmological scanning with non-trivial back reaction

How to Stabilize the Higgs Potential

The spin trick

a particle of spin s: 2s+1 polarization states

...with the only exception of a particle moving at the speed of light

... fewer polarization states

Spin 1 Gauge invariance ⟶ no longitudinal polarization ↘ m=0

Spin 1/2 Chiral symmetry ⟶ only one helicity ↗ m=0

If the symmetries are broken, the radiative mass will be set by the scale of symmetry breaking, not the UV/Planck scale

... but the Higgs is a spin 0 particle

Symmetries to Stabilize a Scalar Potential

Supersymmetry

fermion ~ boson

Higher Dimensional Lorentz invariance

$\Lleftarrow$ gauge-Higgs unification models

[Manton '79, Fairlie 79, Hosotani '83 +...]

$$A_\mu \sim A_5$$

4D spin 1 ↗ A_μ; 4D spin 0 ↖ A_5

These symmetries cannot be exact symmetry of the Nature.
They have to be broken. We want to look for a soft breaking in order to preserve the stabilization of the weak scale.

Other approaches to the hierarchy problem

the hierarchy problem can be reformulated as:
why the weak scale so much smaller than the Planck scale of quantum gravity?

$$M_{\rm Pl} = \sqrt{\frac{\hbar c}{G_{\rm N}}} \sim 10^{19}\,{\rm GeV}/c^2$$

✳ **large extra dimensions (~1mm)**: dilute gravitational interactions into large volume not accessible to other forces. Scale of quantum gravity around 1TeV. Black holes could be produced at the LHC.

✳ **many different species**: $M_* = M_{Pl}/\sqrt{N}$. $M_* \sim 1$TeV if $N \sim 10^{32}$

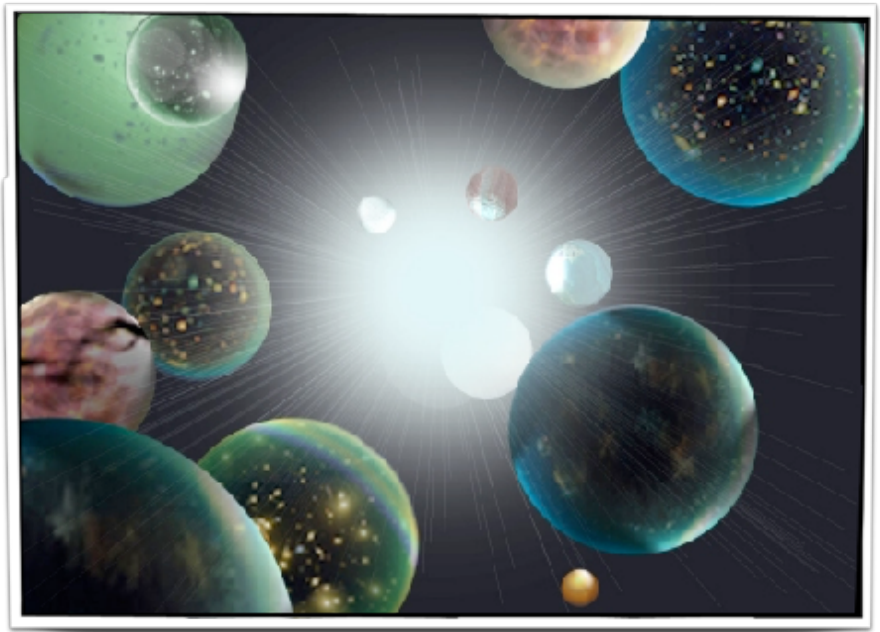
✳ **composite Higgs**: above the scale of compositeness, the Higgs boson dissolves into its fundamental constituents. Momentum-dependent form factors cut off the divergent integrals

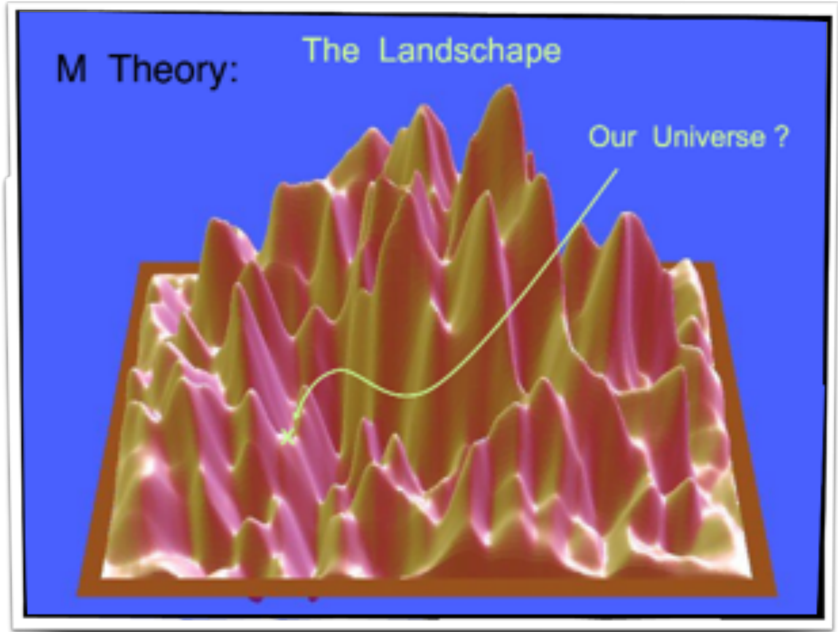
✳ ~~break EW symmetry **without a Higgs boson**, aka technicolor models~~. Ruled out by the Higgs boson discovery

Could the EW scale accidentally small?

The Sun and the Moon have the same angular size seen from Earth. Why?

- Dynamical explanation?
- Accident?
- Multiverse... there exist many (exo)planets with moons!
- Anthropic selection (probably not for the Moon, but maybe for the Higgs)





Number of string vacua: $10^{500 \pm 272\,000}$

Taylor, Wang '15

What is BSM?

?

I don't know. Nobody knows

If it were known, it would be part of the SM!

You won't learn during these lectures what BSM is.

You'll learn (maybe) what BSM could be.

" Looking and not finding is different than not looking"

We'll study the limitations/defaults of the SM as a guide towards BSM.

We want to learn from our failures

What is the scale of New Physics?

High Scale Wishes

small EDMs, FCNC: $\frac{g F_{\mu\nu} \bar{\psi} H \sigma^{\mu\nu} \psi}{M_{\rm NP}^2}$

tiny neutrino masses: $\frac{(LH)^2}{M_{\rm NP}}$

slow proton decay: $\frac{UUDE}{M_{\rm NP}^2}$

Low Scale Wishes

small EDMs: $\mathrm{argdetY} \leq 10^{-10}$

↪ axion?

tiny vacuum energy: $\Lambda \approx M_{\rm NP}^4 \gg \left(10^{-3}\mathrm{eV}\right)^4$

↪ ?

light Higgs boson: $m_H^2 \approx M_{\rm NP}^2 \gg (125\mathrm{GeV})^2$

↪ light susy?

Where is everyone?

even new physics at few hundreds of GeV might be difficult to see and could escape our detection

- **compressed spectra**
- **displaced vertices**
- **no MET, soft decay products, long decay chains**
- **uncoloured new physics**

$\not{R}$-susy

Neutral naturalness
(twin Higgs, folded susy)

Relaxion