Higgs physics at the LHC

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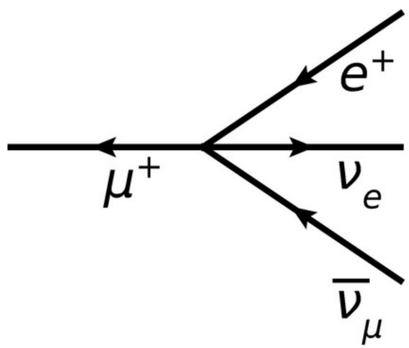
Université de Genève

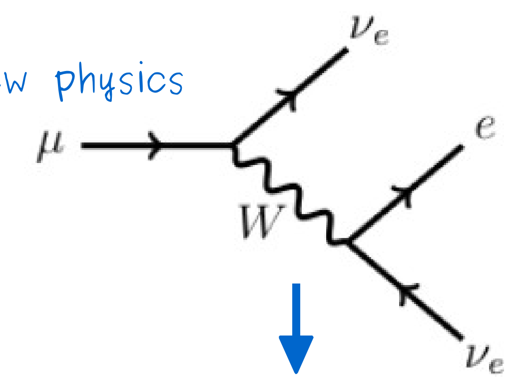
Interpreting the LHC Run 2 data and beyond
May 2019

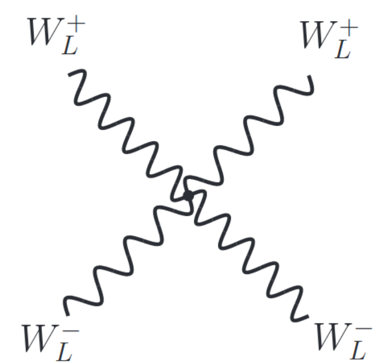
SM's own demise:



$$\sim G_F = \frac{1}{\sqrt{2}(246\ GeV)^2}$$

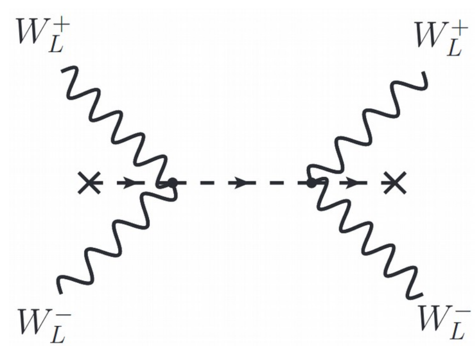
Muon decay signals
the existence of new physics

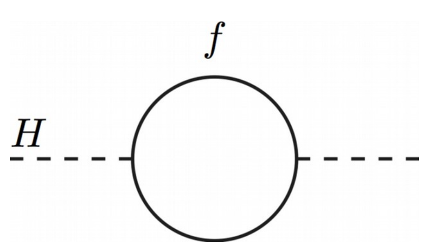




$$\mathcal{A}(\phi^+\phi^+\phi^-\phi^-) \sim \frac{s}{v^2}$$

Inconsistency of W scattering
implies the need for a
unitarization mechanism



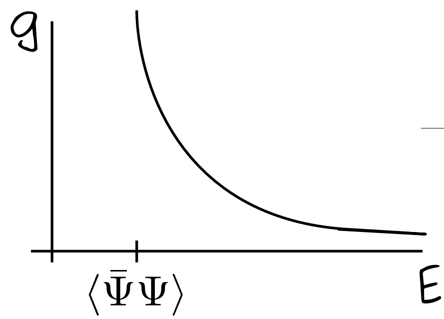


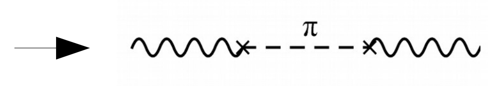
$$\sim \frac{y_t^2 N_c}{16\pi^2}\Lambda^2$$

Higgs mass cannot be computed but estimated:
The estimation tells you that
There must be **more stuff** at the EW scale

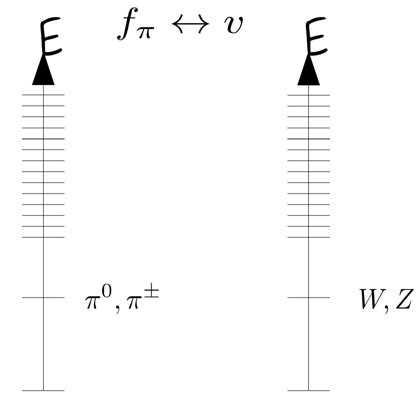
Nature’s options

Technicolor: a heavier copy
of QCD can induce EWSB

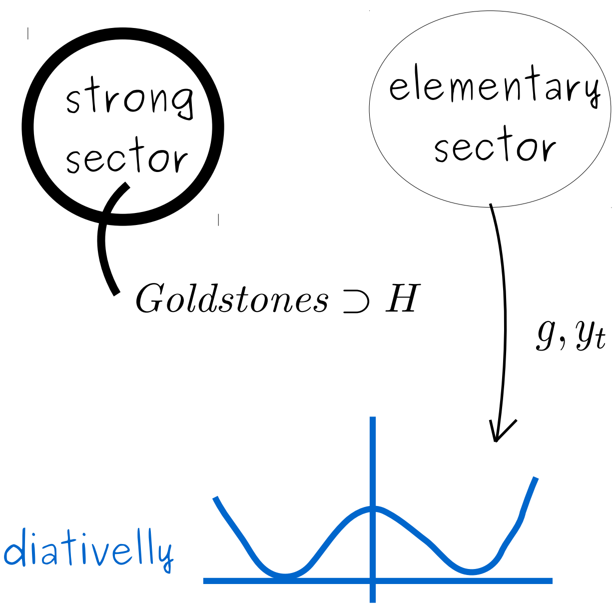


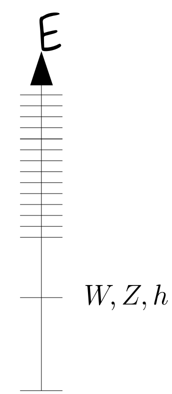


$$m_W = \frac{1}{2} g f_\pi$$



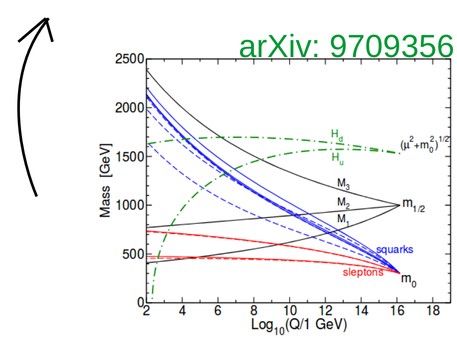
Higgs as a Nambu–Goldstone boson

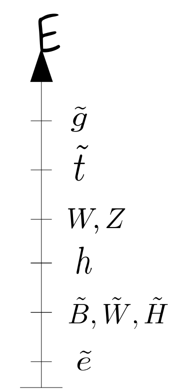




EWBS is
generated radiativelly

Supersymmetry: no quadratic divergences
Dark matter
GUT & gravity

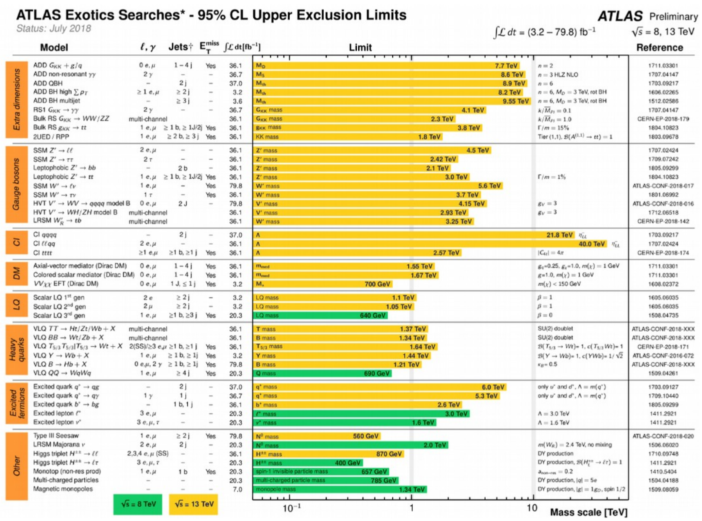




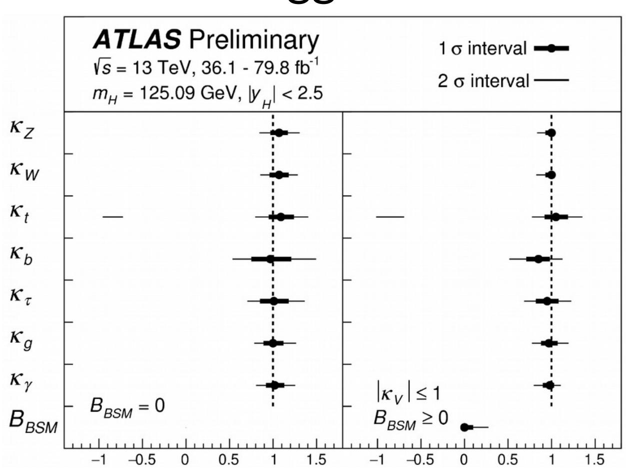
Introduction

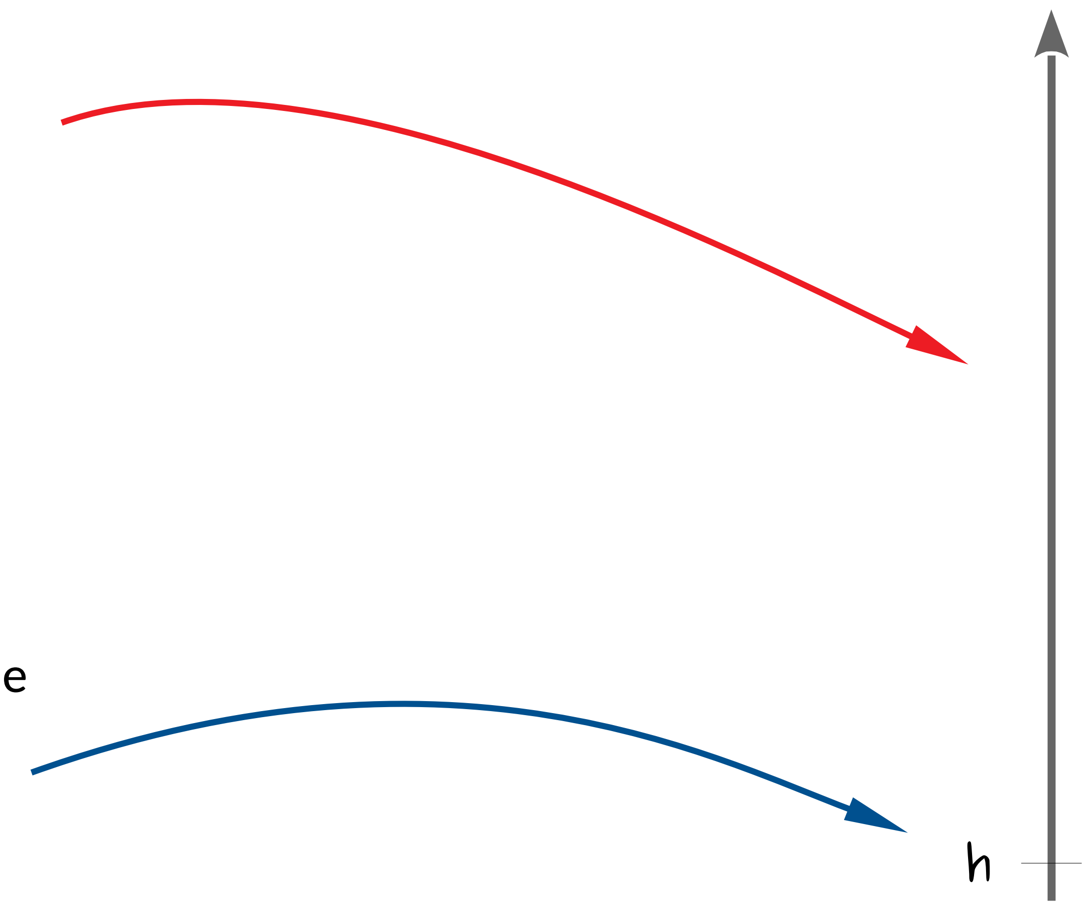
The two major discoveries of the LHC:

- An *apparent* mass gap above the EW scale



- A light scalar *apparently* compatible with the SM Higgs boson





$$V = \mu^2 H^2 + \lambda H^4$$

SM Higgs is not an explanation of EWSB, just a parametrization.

Why sacrifice so much for simplicity?
Why is the EW scale so special?

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SM Higgs is not an explanation of EWSB, just a parametrization.

Why sacrifice so much for simplicity?
Why is the EW scale so special?

LHC in the LEP tunnel Vol. 1, 1984

been solved. We now confront deeper problems - the origin of mass, the choice of fundamental building blocks (the problem of flavour), the question of further unification of forces including gravity, the origin of charge and of gauge symmetry. It is only to be expected that many of the first attempts to grapple with these problems will be misguided. As ever, we must reply on experiment to reveal the truth. While we wait for further

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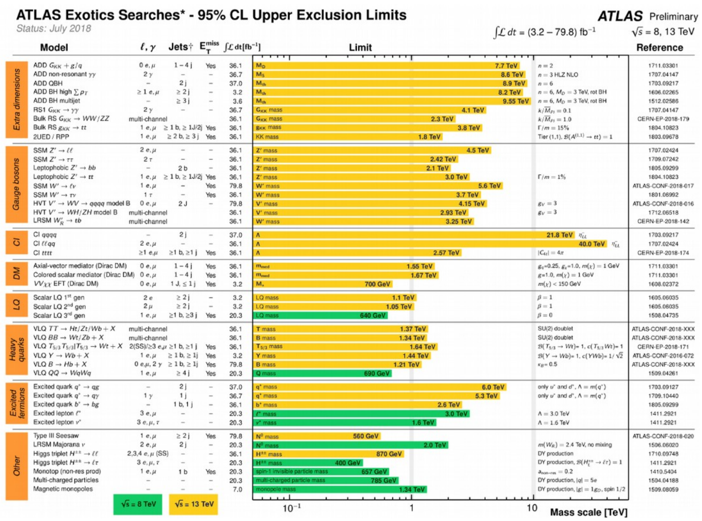

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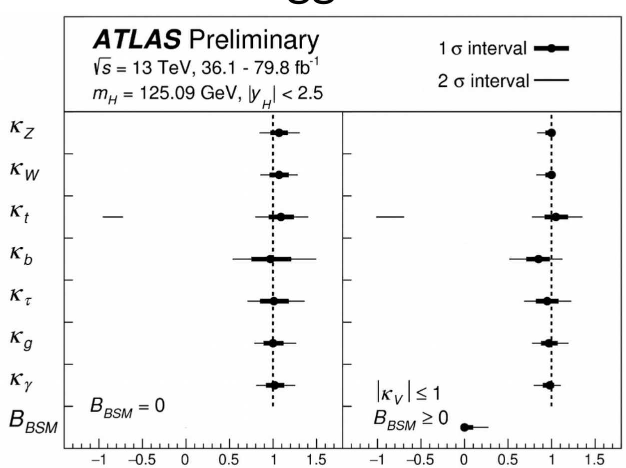
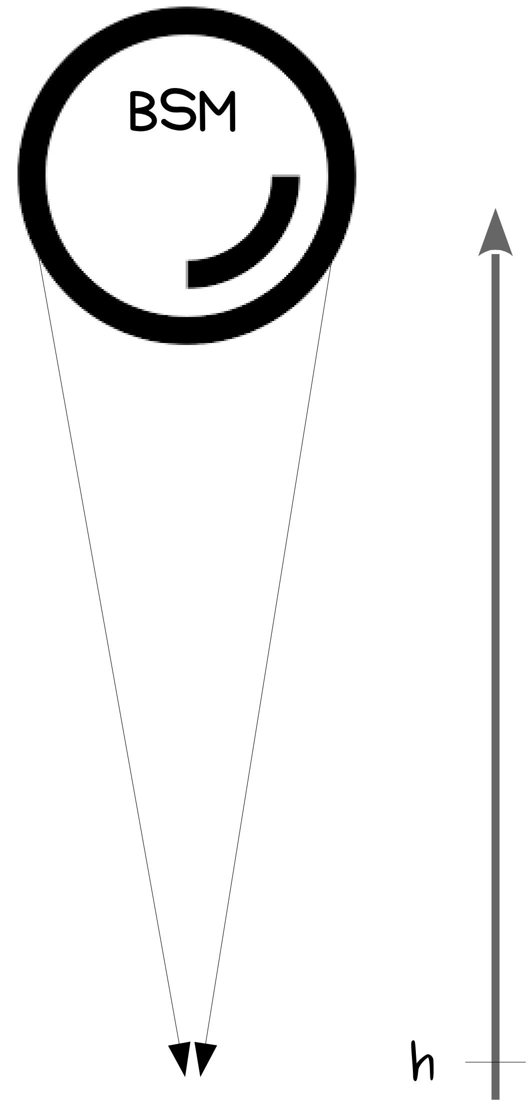


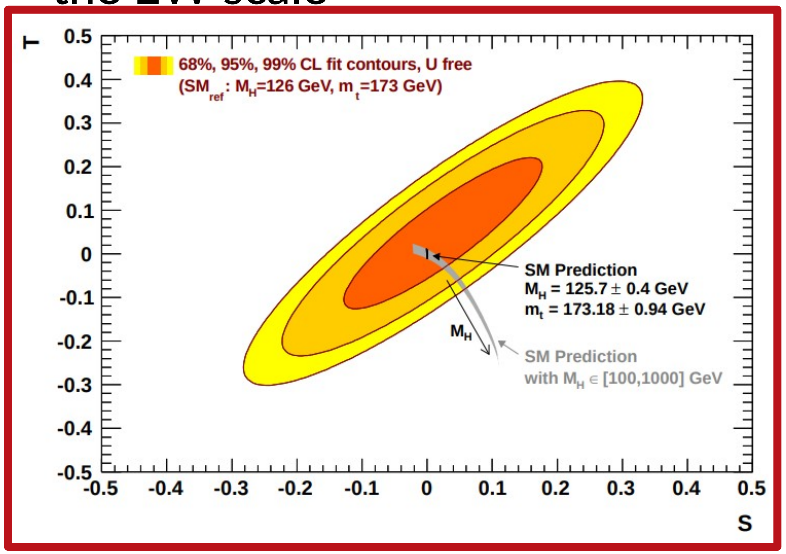


$$\mathcal{L} = \mathcal{L}_{SM} + \frac{1}{\Lambda^2} \sum \mathcal{O}_{d=6} + \dots$$

Introduction

Both discoverries were suggested by precision measurements

- An *apparent* mass gap above the EW scale



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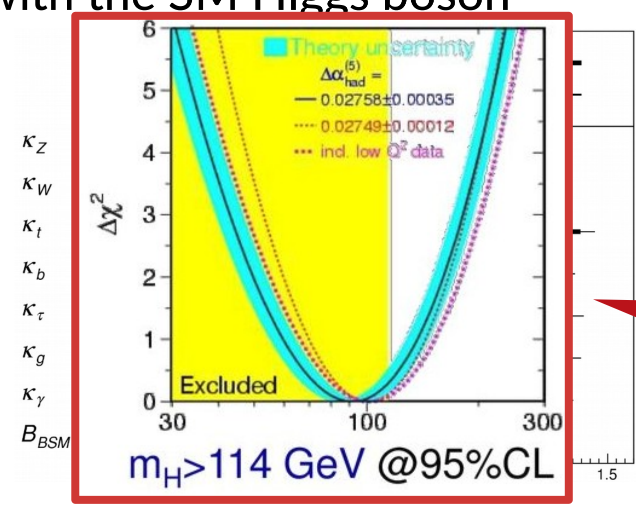

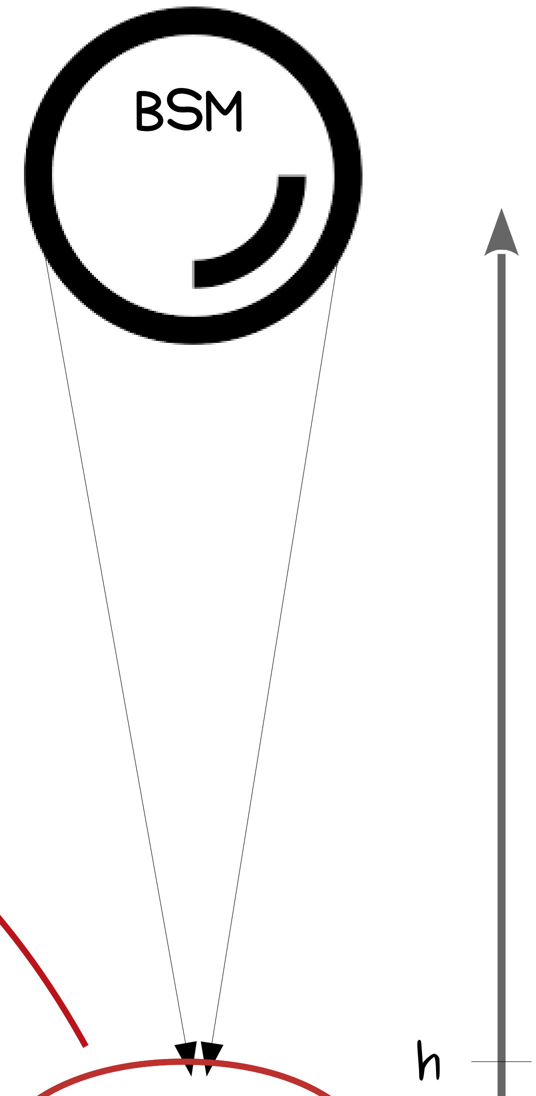

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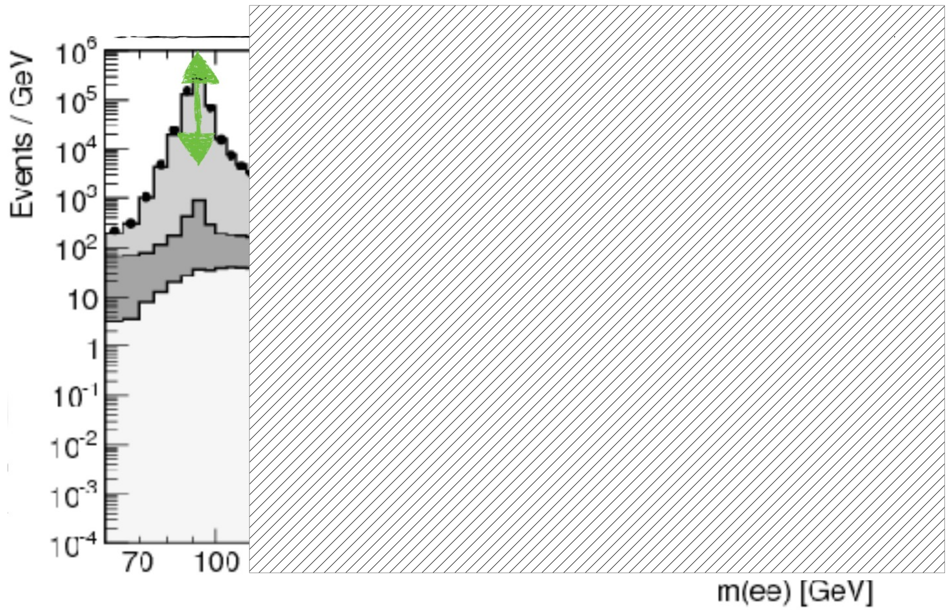
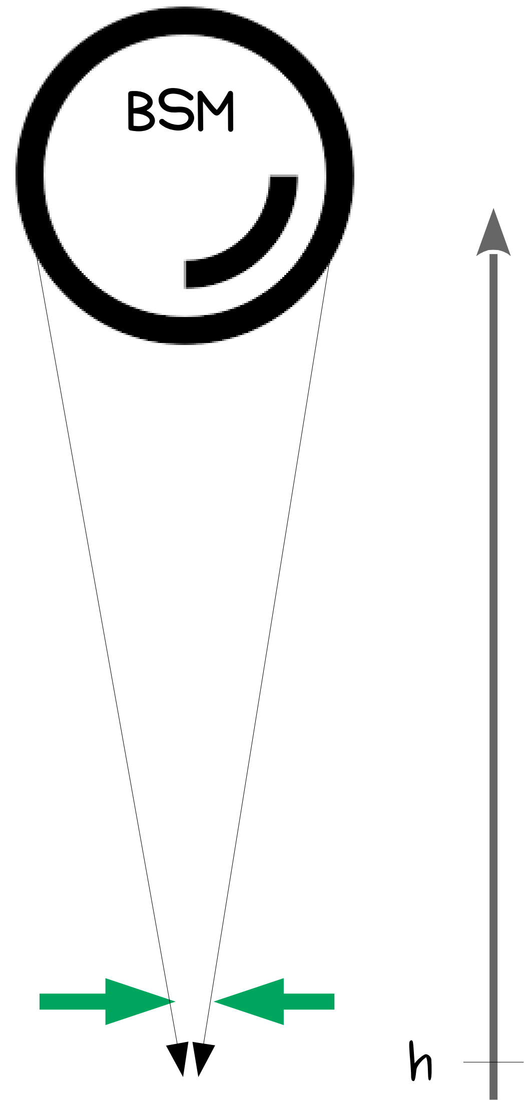


Giudice, Grojean, Pomarol, Rattazzi, '07

For example, for composite Higgs models, LEP constraints already told us that

$$m_\rho \geq 3 \text{ TeV} \qquad \Lambda_{cust} \geq 10 \text{ TeV}$$



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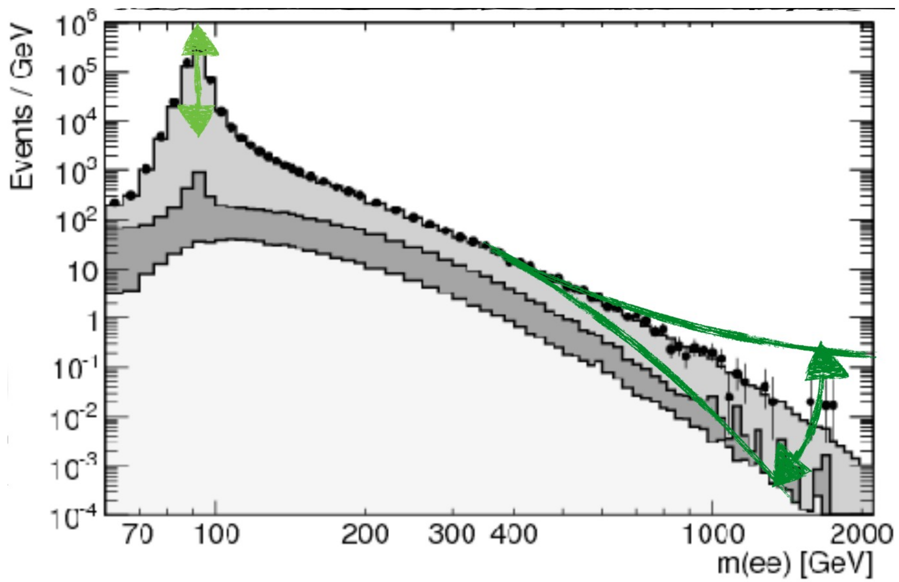
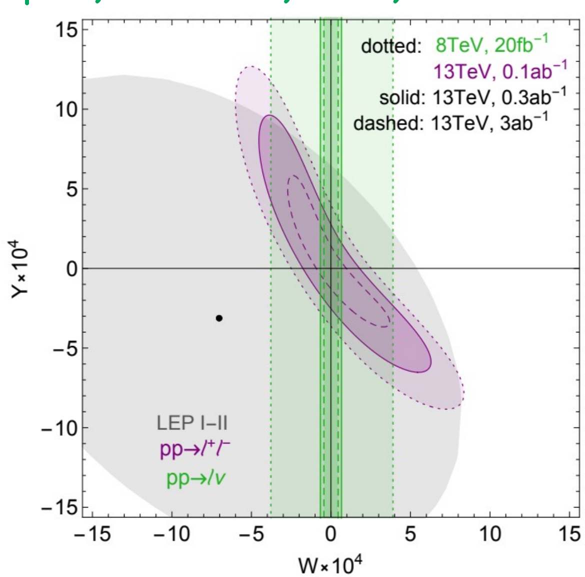
Introduction

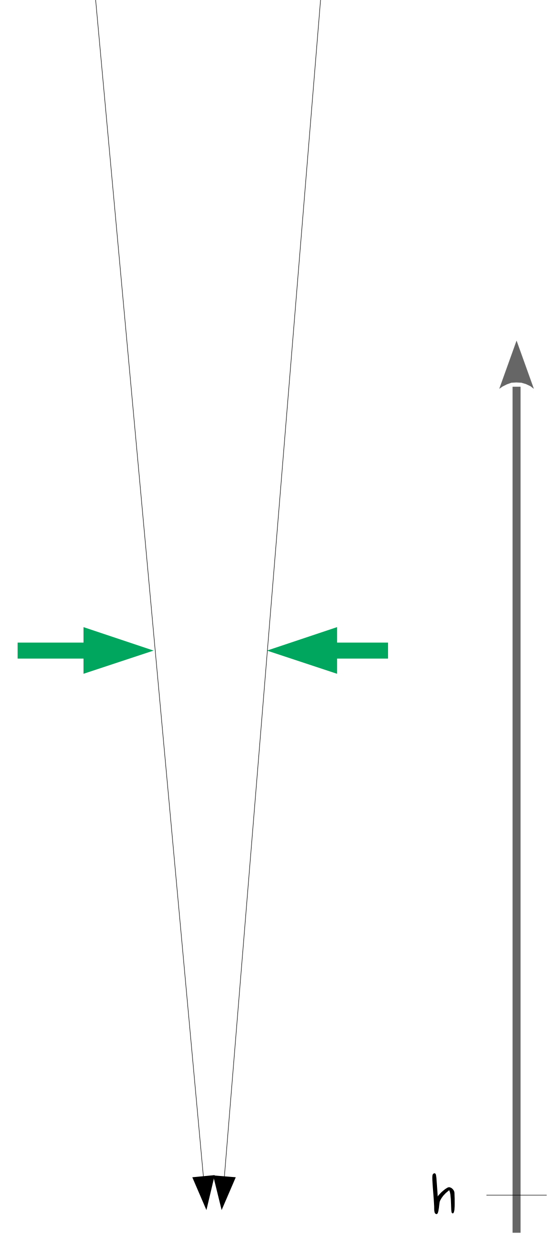
Can we continue this program at LHC?

Yes, «energy helps accuracy»



Farina, Panico, Pappadopulo, Ruderman, Torre, Wulzer '16



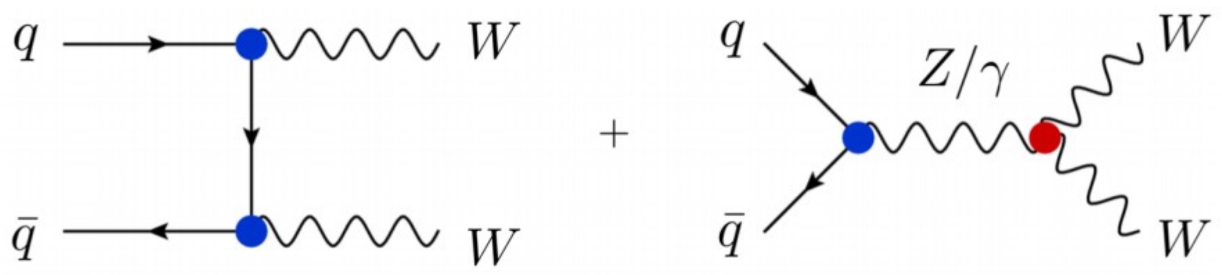


$$\mathcal{L} = \mathcal{L}_{SM} + \frac{1}{\Lambda^2} \sum \mathcal{O}_{d=6} + \ldots$$

An example in diboson

An explicit example in diboson:

In the unitary gauge, and in the SM,



$$\mathcal{M}_\gamma + \mathcal{M}_Z + \mathcal{M}_t = -i\frac{e^2 \sin\theta}{2m_W^2} s \left(Q_q + \frac{1}{s_W^2}(T_q^3 - s_W^2 Q_q) - \frac{T_q^3}{s_W^2} \right)$$

- Each of the contributions separately grows with energy

- In the SM, the couplings are such that there is no pathological growth of the amplitude

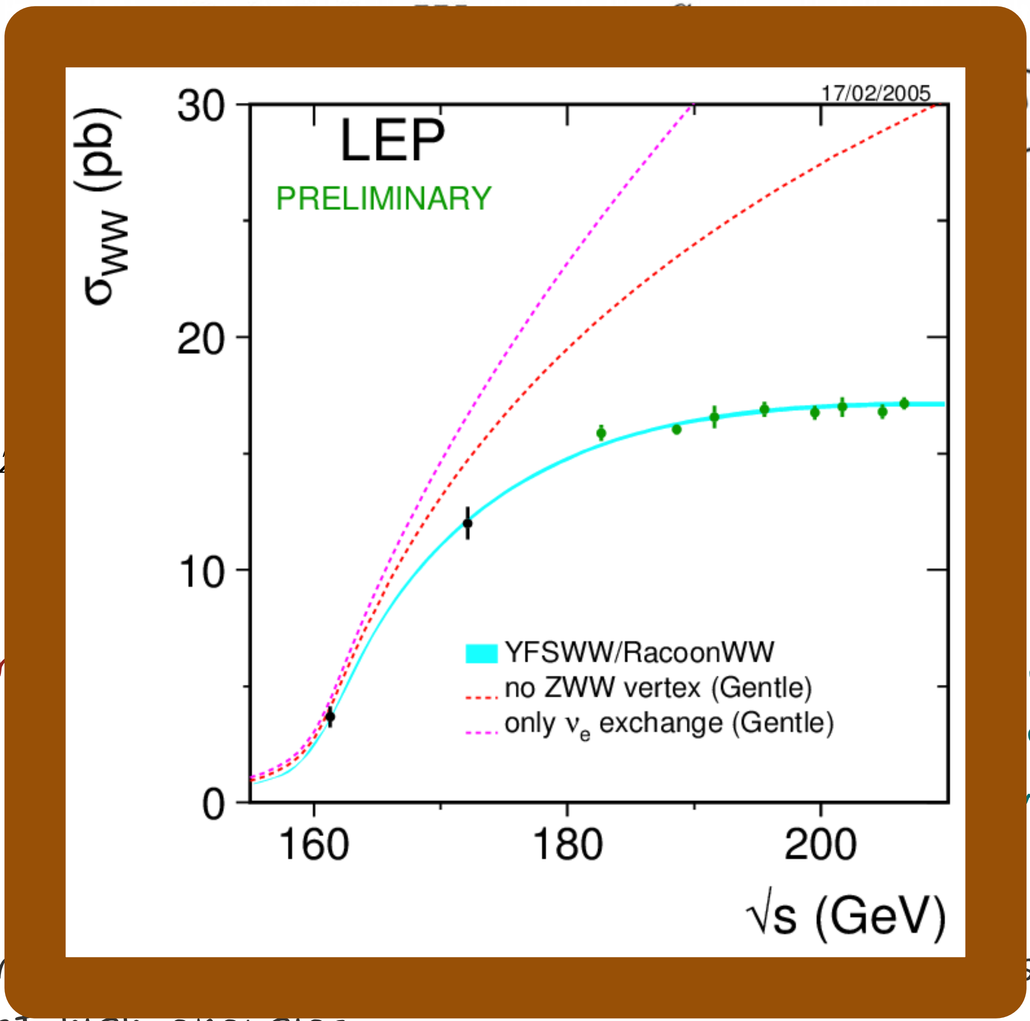
- This also means that non-SM couplings induce deviations that get amplified at high energies

An example in diboson

An explicit example in diboson:

In the unitary gauge, and in the SM,

q W W $\bar{q}$

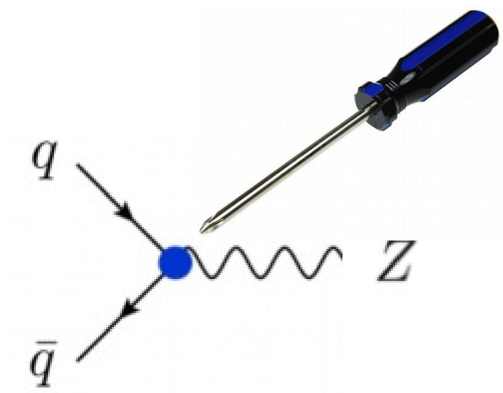


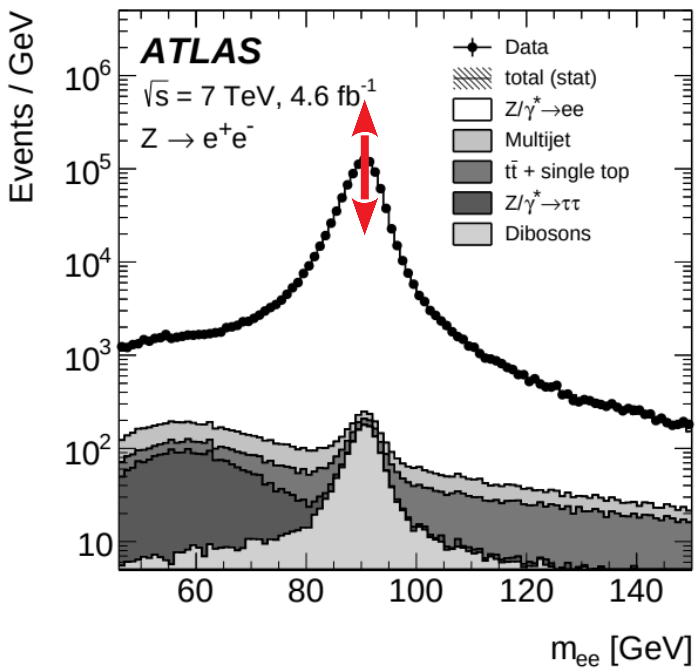
$\mathcal{M}_\gamma + \mathcal{M}_Z$ ... $- \frac{T_q^3}{s_W^2}\Big)$

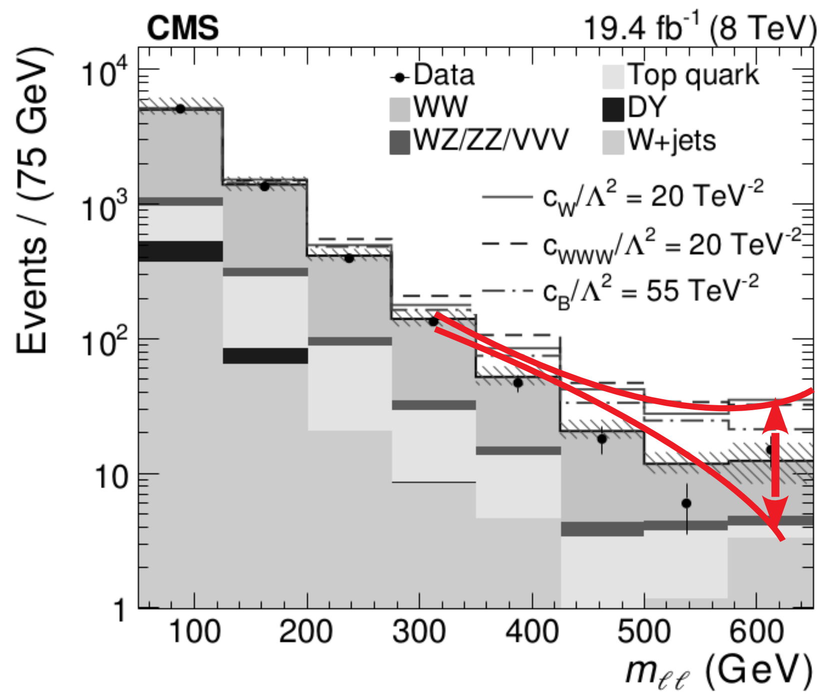
– Each of th... couplings separately ... ere is no energy ... wth of

– This also m... that get amplified at high energies

An example in diboson







Constant shift of cross section
Limited by systematics

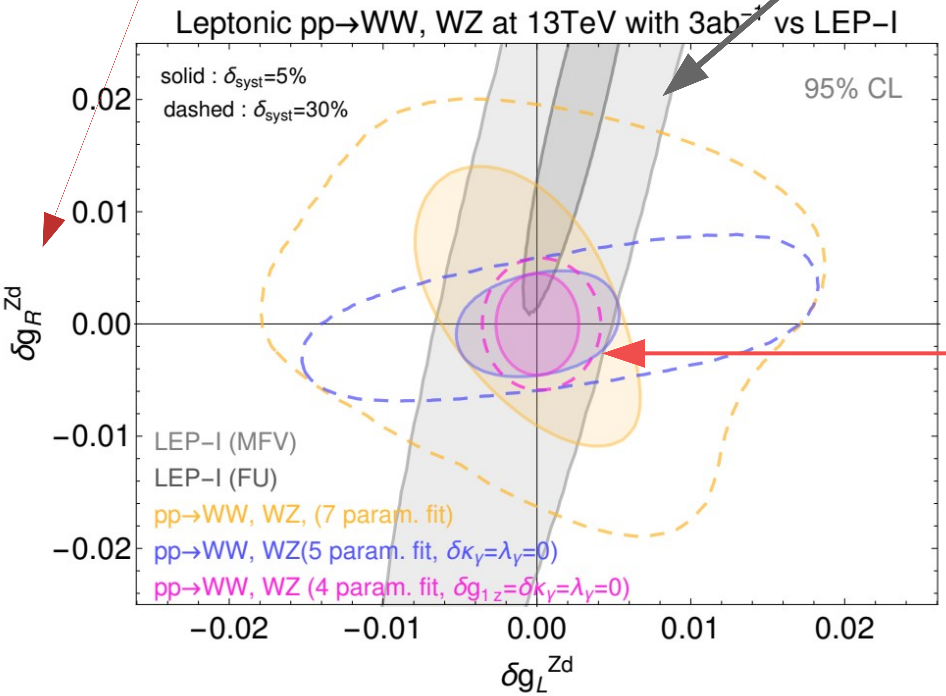
Effects enhanced at high energies
Limited by statistics

An example in diboson

Grojean, Montull, MR, '18

$$\sqrt{g^2+g'^2}Z_\mu \bar{f}_R\gamma_\mu\left(-s_W^2 Q_f+\delta g_R^{Zf}\right)f_R$$

LEP, Z pole measurements



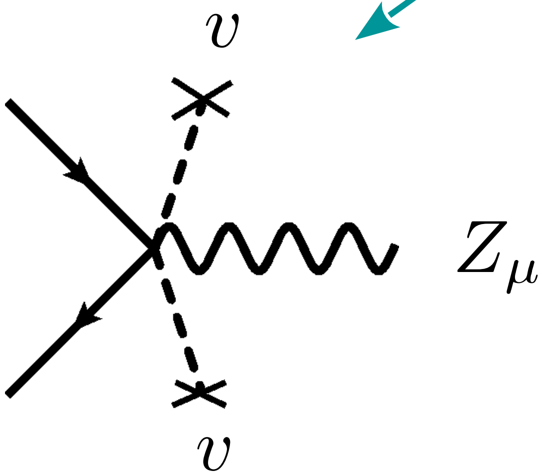
HL-LHC, diboson

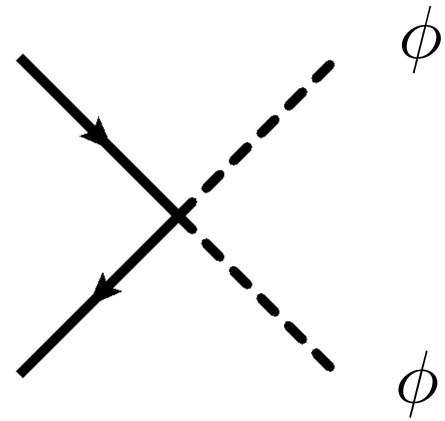
$$\sqrt{g^2+g'^2}Z_\mu \bar{f}_L\gamma_\mu\left(T_f^3-s_W^2 Q_f+\delta g_L^{Zf}\right)f_L$$

An example in diboson

From an EFT perspective, it is clear in the Feynman gauge, where the Goldstone bosons are manifest

$$\bar{f}\gamma_\mu f\, H^\dagger \overleftrightarrow{D}_\mu H$$





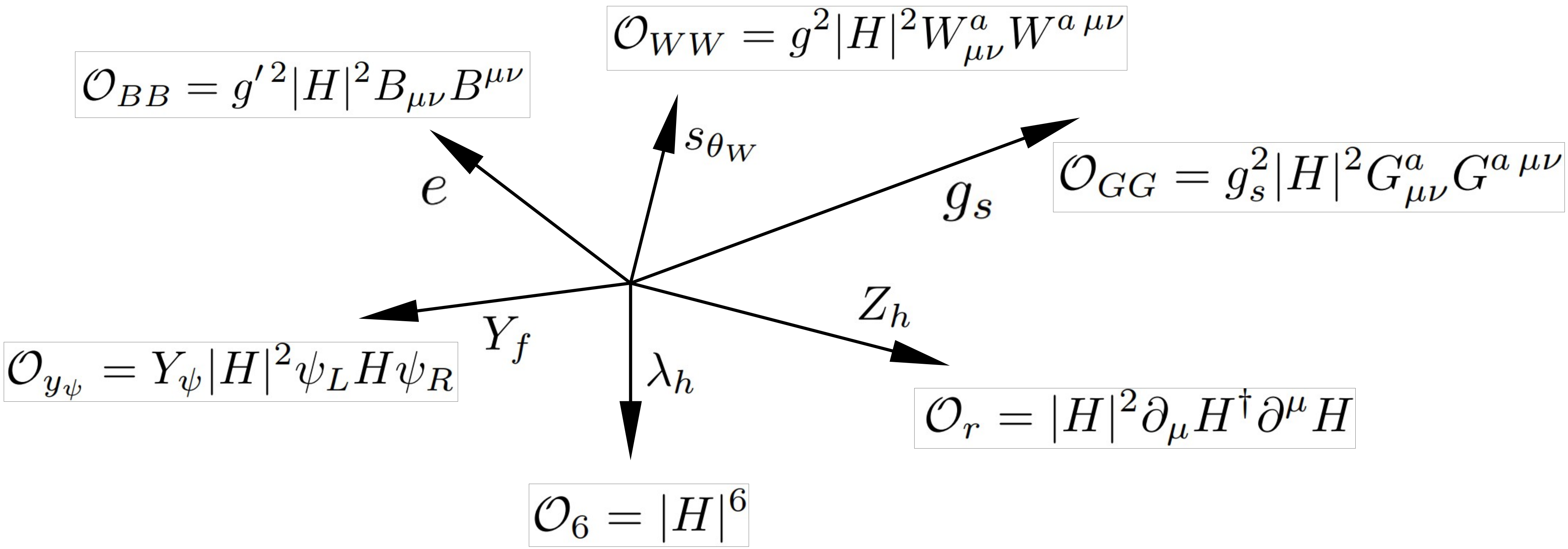
$$\delta\mathcal{A} \sim v^2/\Lambda^2 \qquad\qquad \delta\mathcal{A} \sim E^2/\Lambda^2$$

Gupta, Pomarol, Riva, '14
Masso, '14

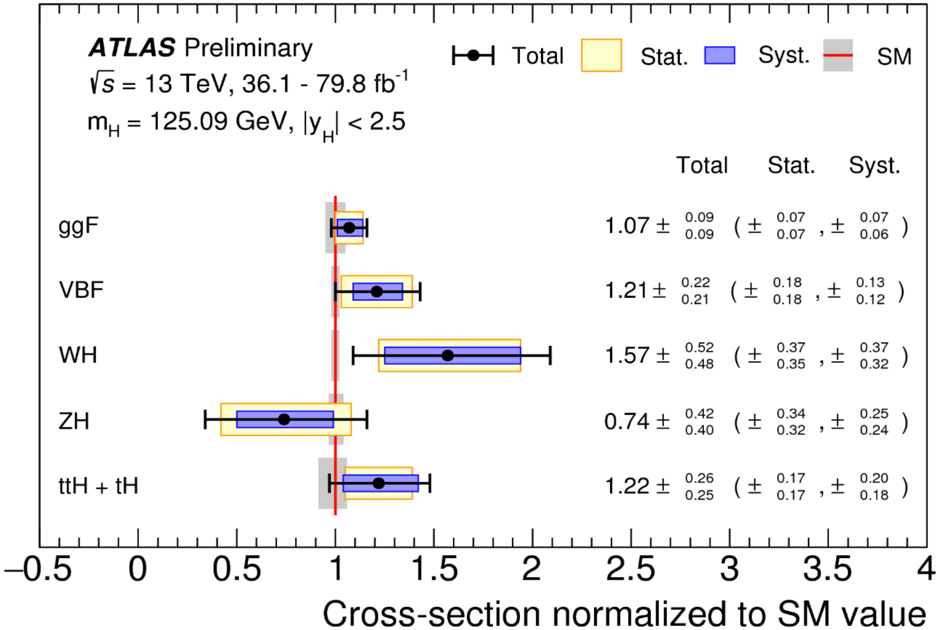
But now we have a new guy in the spectrum.
The Higgs probes a sector untested before:

Each SM input defines a direction only probed by Higgs physics, they look like

$$|H|^2 \mathcal{O}_{SM}$$

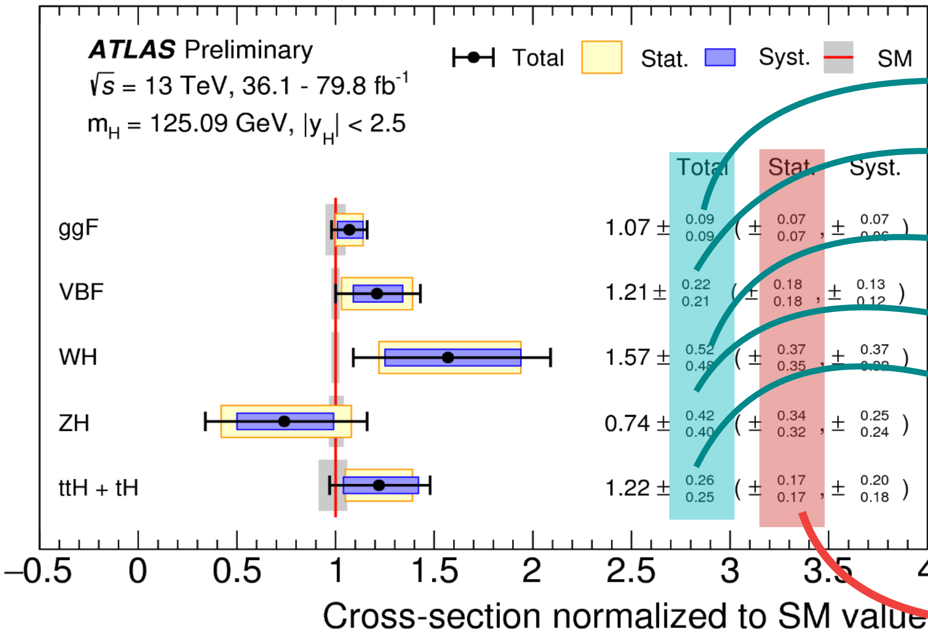


Higgs with Higgs



The directions defined by these Higgs operators are constrained by measuring the *on-shell* Higgs production rates and its branching ratios

Higgs with Higgs



HL-LHC projections:

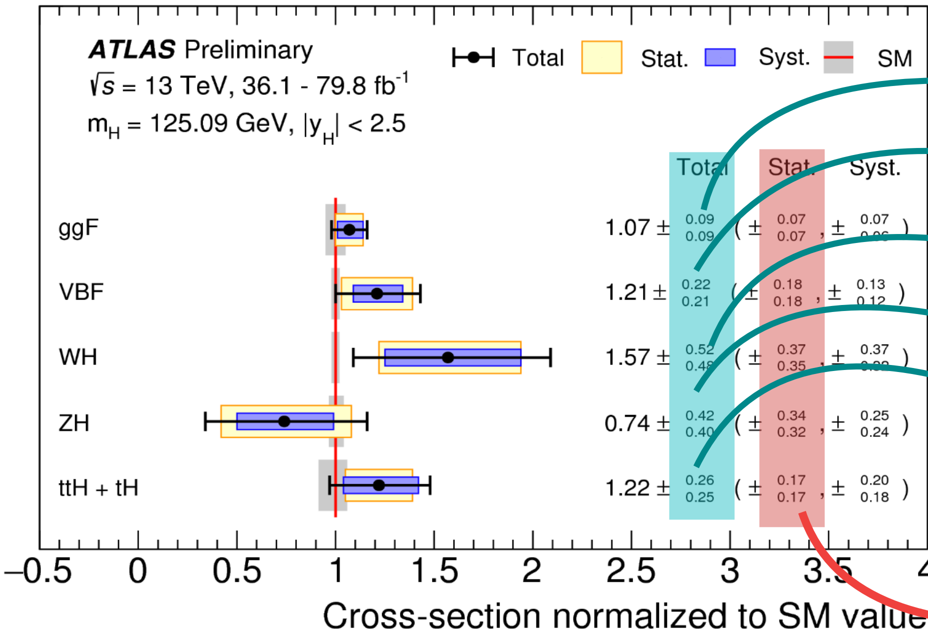
ATLAS

		3000 fb^{-1} uncertainty [%]				
		Total	Stat	Exp	SigTh	BkgTh
σ_{ggH}	S1	3.5	0.8	2.1	2.1	1.6
	S2	2.4	0.8	1.7	1.2	1.0
σ_{VBF}	S1	5.5	2.0	2.7	3.7	2.1
	S2	4.2	2.0	2.3	2.2	1.7
σ_{WH}	S1	9.3	4.0	4.0	5.1	5.4
	S2	7.7	4.0	3.4	3.3	4.5
σ_{ZH}	S1	6.2	3.4	2.4	3.4	3.0
	S2	4.8	3.4	1.8	2.0	2.1
σ_{ttH}	S1	6.7	1.9	3.1	3.7	4.3
	S2	5.3	1.9	2.8	2.4	3.3

On-shell Higgs coupling (HC) measurements will be saturated by systematics:

- will not benefit from collecting more luminosity
- inclusive rates will not benefit from going to higher collider energies

Higgs with Higgs



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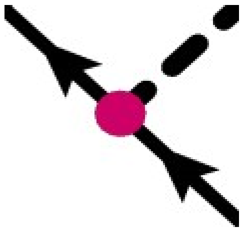
On-shell Higgs coupling (HC) measurements will be saturated by systematics:
- › will not benefit from collecting more luminosity
- › inclusive rates will not benefit from going to higher collider energies

This talk is about a program to measure Higgs properties in a way that
- – It is limited by statistics, i.e., it does benefit from larger luminosities
- – It benefits from going at higher collider energies, crucial for HE-LHC, CLIC, FCC/SppC

Higgs without Higgs

Tha same logic we applied to diboson can be applied to Higgs couplings:



$$\delta\mathcal{A}/\mathcal{A} \sim v^2/\Lambda^2$$

there must be some process where
an anomalous Yukawa induces
a pathological growth in energy…

$$|H|^2 \bar{f}_L H f_R$$

Higgs without Higgs

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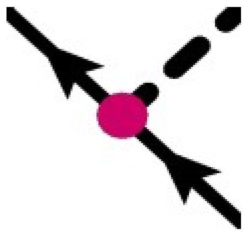
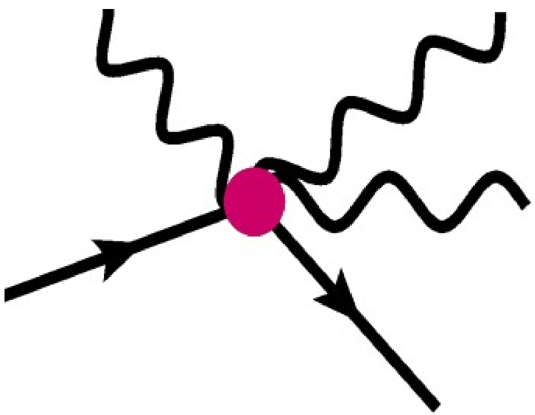


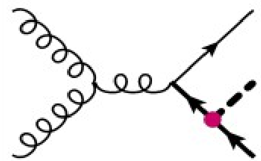
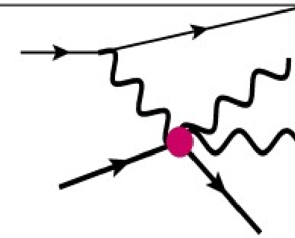
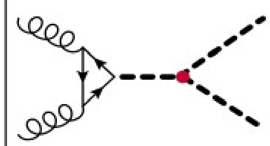
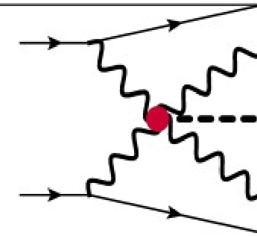
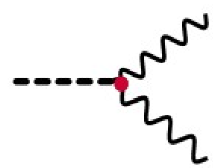
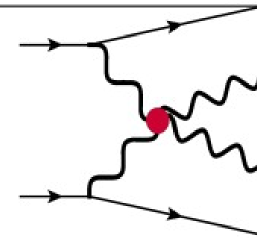
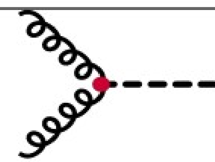
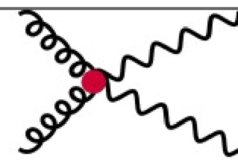
$$\delta\mathcal{A}/\mathcal{A} \sim v^2/\Lambda^2$$

$$|H|^2 \bar{f}_L H f_R$$



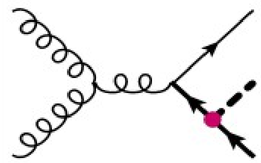
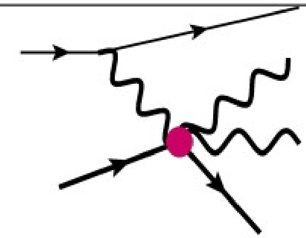
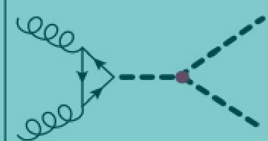
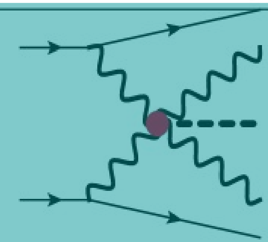
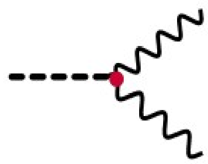
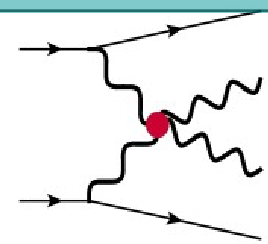
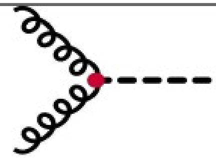
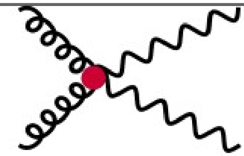
unanchor the Higgs from its vev

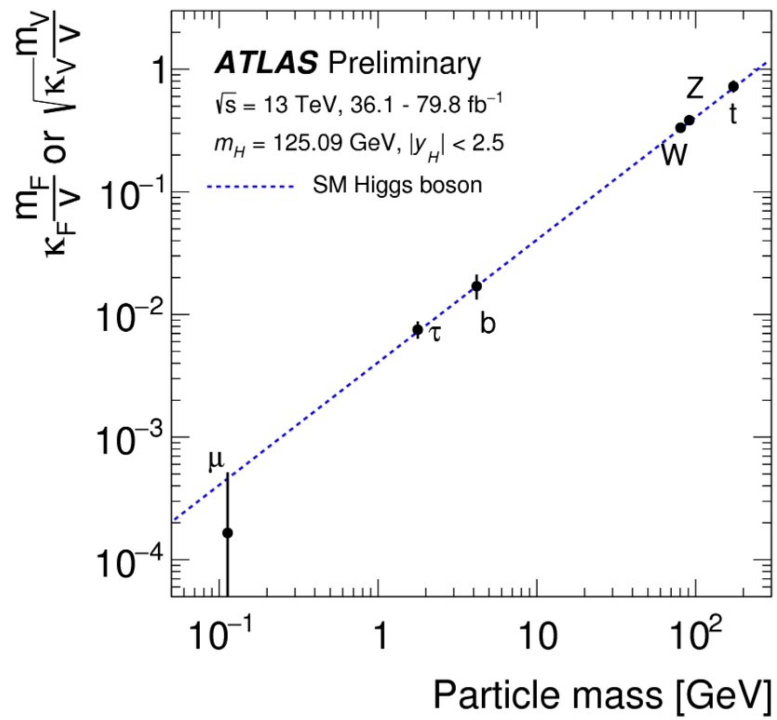
$$\boxed{\delta\mathcal{A}/\mathcal{A} \sim E^2/\Lambda^2}$$

		HC	HwH	Growth
κ_t	$\mathcal{O}_{y_t}$			$\sim \frac{E^2}{\Lambda^2}$
κ_λ	$\mathcal{O}_6$			$\sim \frac{vE}{\Lambda^2}$
$\kappa_{Z\gamma}$ $\kappa_{\gamma\gamma}$ κ_V	$\mathcal{O}_{WW}$ $\mathcal{O}_{BB}$ $\mathcal{O}_r$			$\sim \frac{E^2}{\Lambda^2}$
κ_g	$\mathcal{O}_{gg}$			$\sim \frac{E^2}{\Lambda^2}$

This puts in correspondence Higgs operators with High Energy, multiboson processes with enhanced sensitivity

Higgs self-coupling

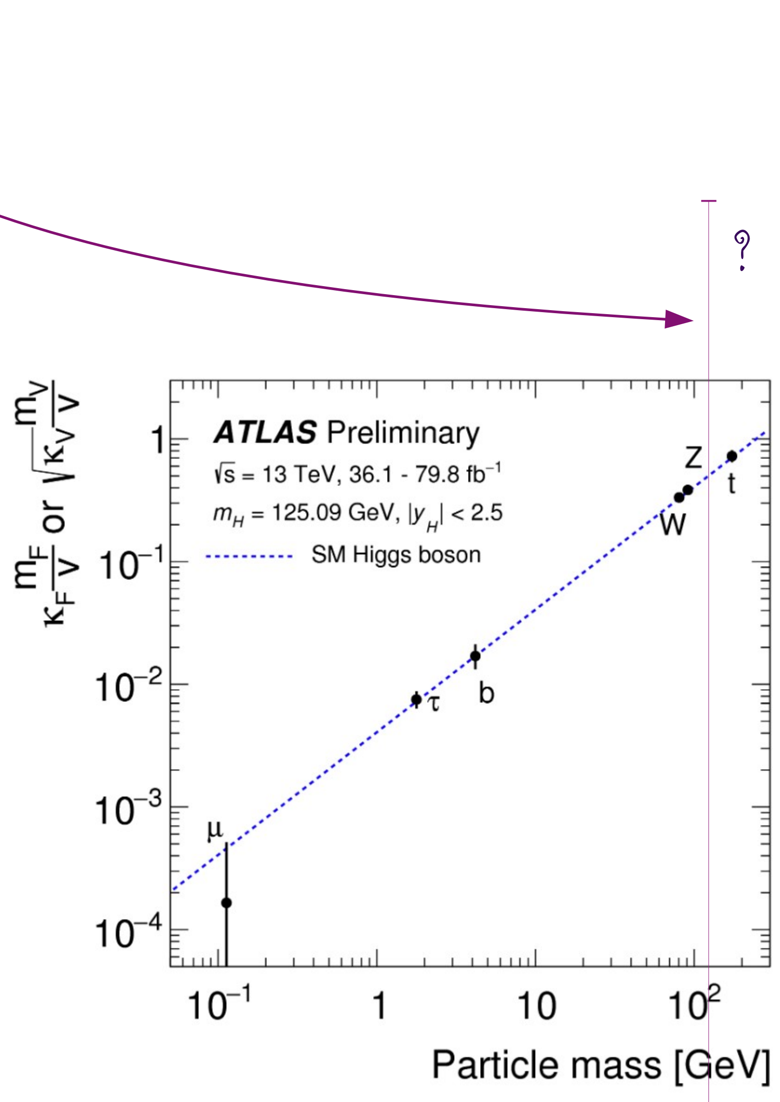
		HC	HwH	Growth
κ_t	$\mathcal{O}_{y_t}$			$\sim \frac{E^2}{\Lambda^2}$
κ_λ	$\mathcal{O}_6$			$\sim \frac{vE}{\Lambda^2}$
$\kappa_{Z\gamma}$ $\kappa_{\gamma\gamma}$ κ_V	$\mathcal{O}_{WW}$ $\mathcal{O}_{BB}$ $\mathcal{O}_r$			$\sim \frac{E^2}{\Lambda^2}$
κ_g	$\mathcal{O}_{gg}$			$\sim \frac{E^2}{\Lambda^2}$



ATLAS Preliminary
√s = 13 TeV, 36.1 - 79.8 fb⁻¹
m_H = 125.09 GeV, |y_H| < 2.5
SM Higgs boson
Z
t
W
b
τ
μ
κ_F m_F/v or √κ_V m_V/v
1
10⁻¹
10⁻²
10⁻³
10⁻⁴
10⁻¹
1
10
10²
Particle mass [GeV]

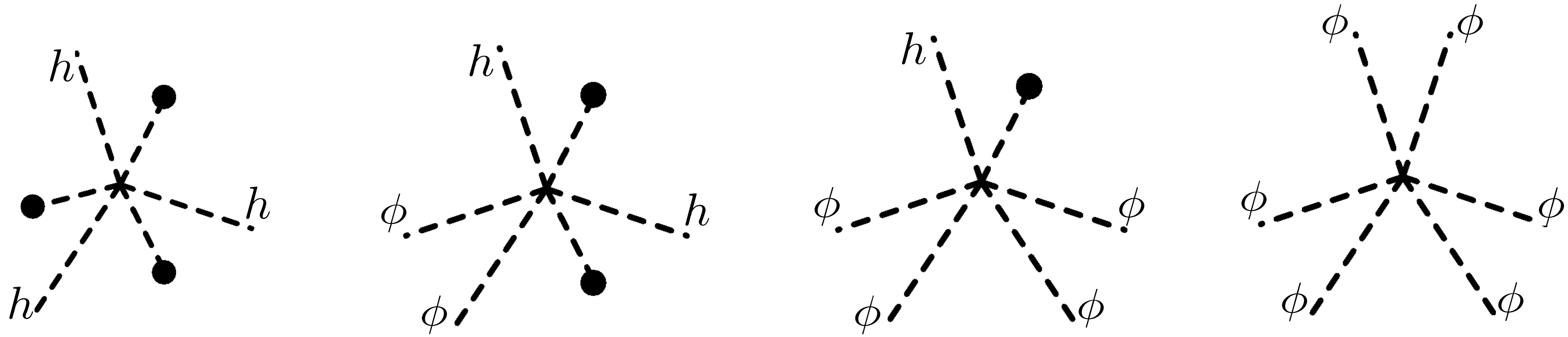
Higgs self-coupling

$$\frac{1}{\Lambda^2}|H|^6$$



Higgs self-coupling

$$\frac{1}{\Lambda^2}|H|^6 \supset \frac{1}{\Lambda^2}\left(v^3 h^3 + 3v^2 h^2 \phi^2 + 3vh\phi^4 + \phi^6 + \dots \right)$$



Higgs self-coupling

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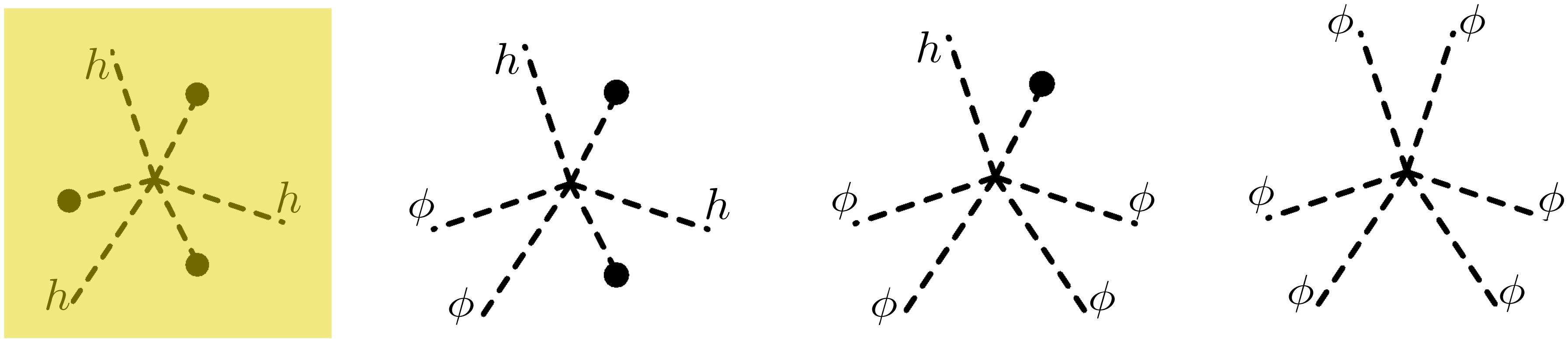
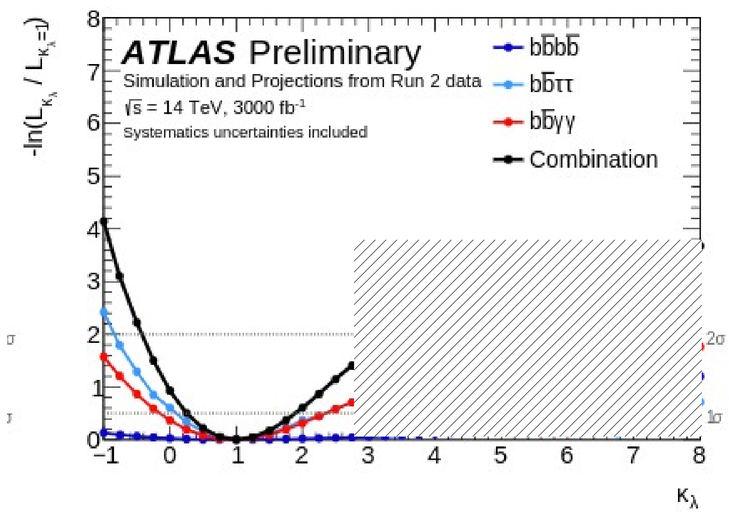


$$\frac{\sigma(pp \to hh)}{\sigma(pp \to h)} \sim 10^{-3} \qquad \mathrm{Br}(h \to b\bar{b}) \times \mathrm{Br}(h \to \gamma\gamma) \sim 60\% \times 0.1\%$$

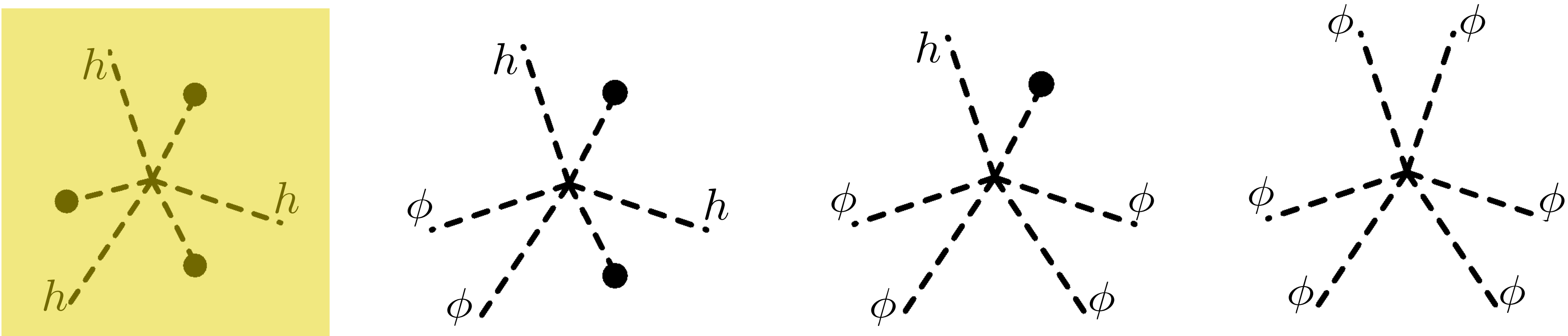


HL-LHC @ 3 ab^{-1}, 95% CL

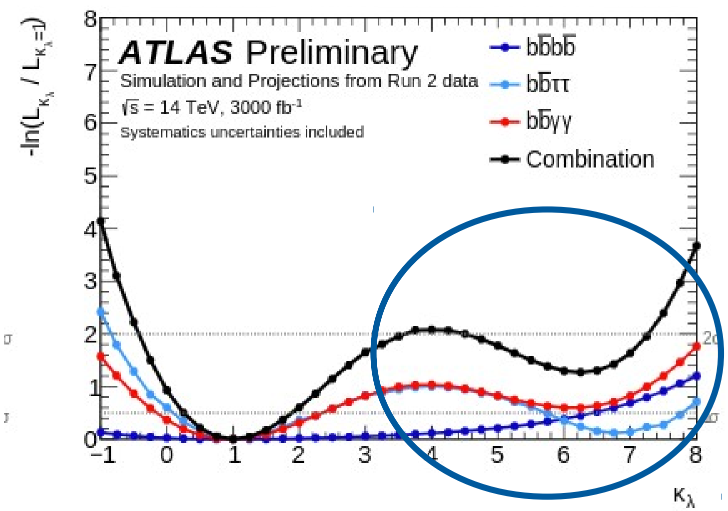
$$\kappa_\lambda \in \sim [-0.5, 3]\,?$$

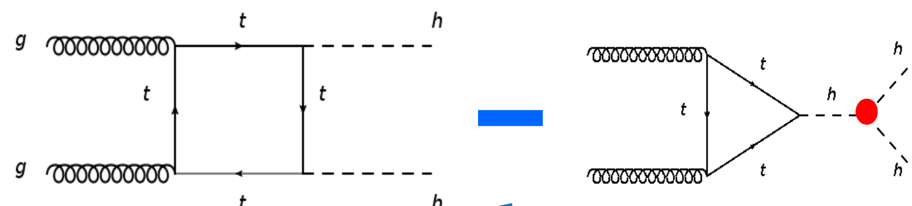
Higgs self-coupling

$$\frac{1}{\Lambda^2}|H|^6 \supset \frac{1}{\Lambda^2}(v^3h^3 + 3v^2h^2\phi^2 + 3vh\phi^4 + \phi^6 + \dots)$$



$$\frac{\sigma(pp \to hh)}{\sigma(pp \to h)} \sim 10^{-3} \qquad \mathrm{Br}(h \to b\bar{b}) \times \mathrm{Br}(h \to \gamma\gamma) \sim 60\% \times 0.1\%$$





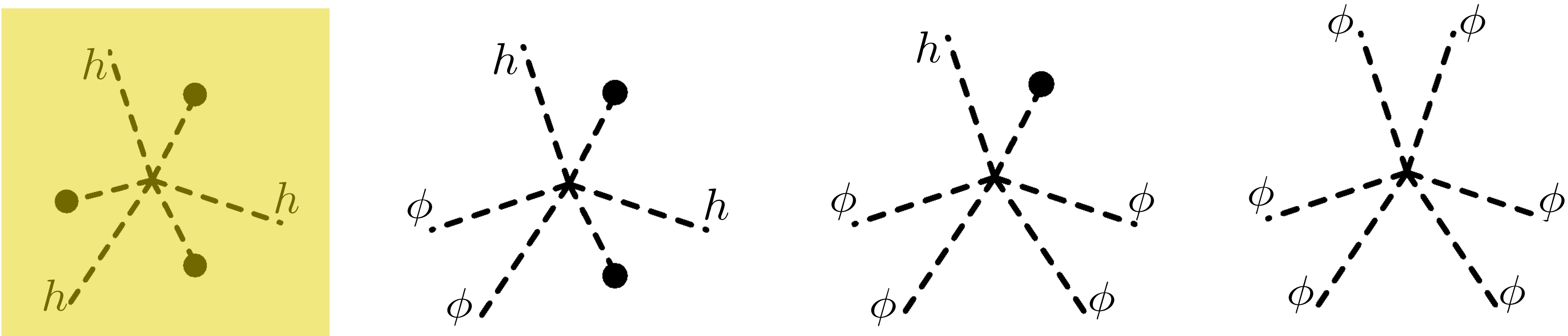
HL-LHC @ 3 ab^{-1}, 95% CL

$\kappa_\lambda \in\sim [-0.5, \not{3}]$?

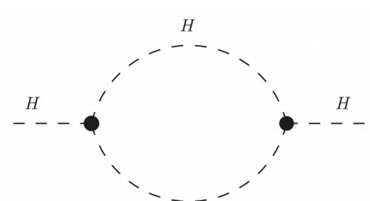
7!

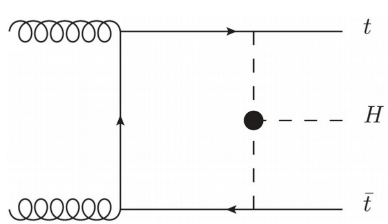
Higgs self-coupling

$$\frac{1}{\Lambda^2}|H|^6 \supset \frac{1}{\Lambda^2}\left(v^3h^3 + 3v^2h^2\phi^2 + 3vh\phi^4 + \phi^6 + \dots\right)$$

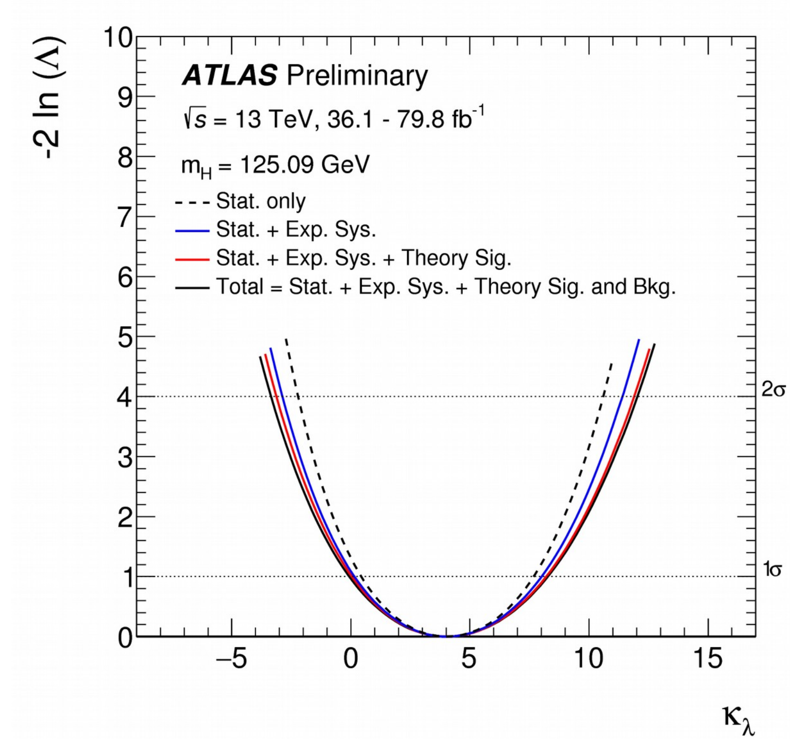


Reinterpretation of single Higgs processes:





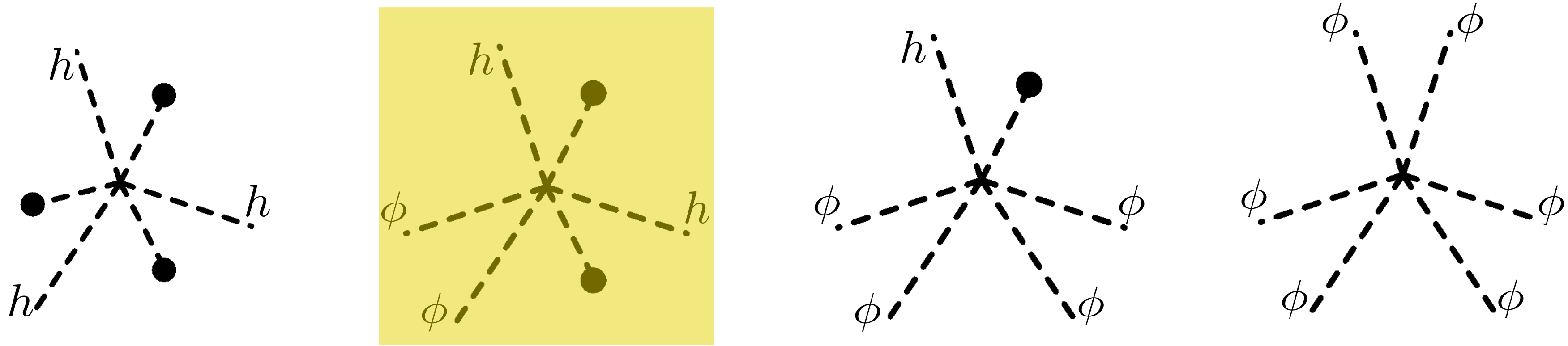
ATL-PHYS-PUB-2019-009



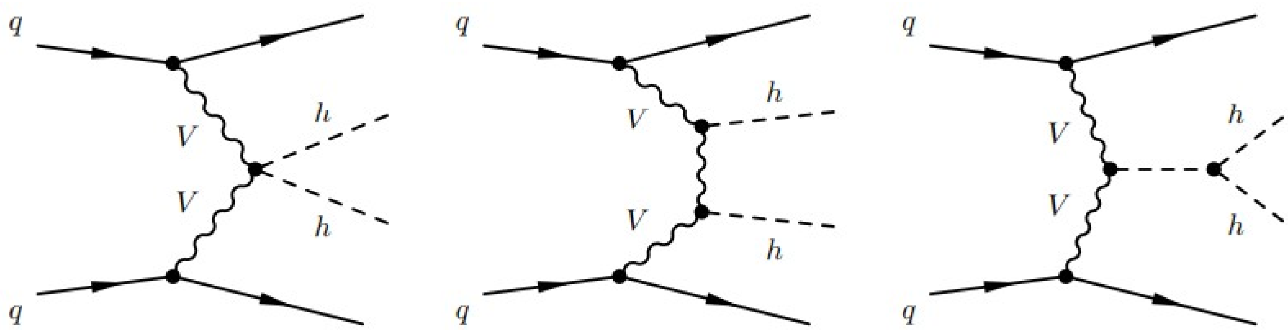
Large flat directions when other Higgs coupling deformations enter.
Global fit to differential observables needed

Higgs self-coupling

$$\frac{1}{\Lambda^2}|H|^6 \supset \frac{1}{\Lambda^2}(\, v^3 h^3 \; + 3v^2h^2\phi^2 + 3vh\phi^4 \; + \; \phi^6 \; + \; \ldots)$$



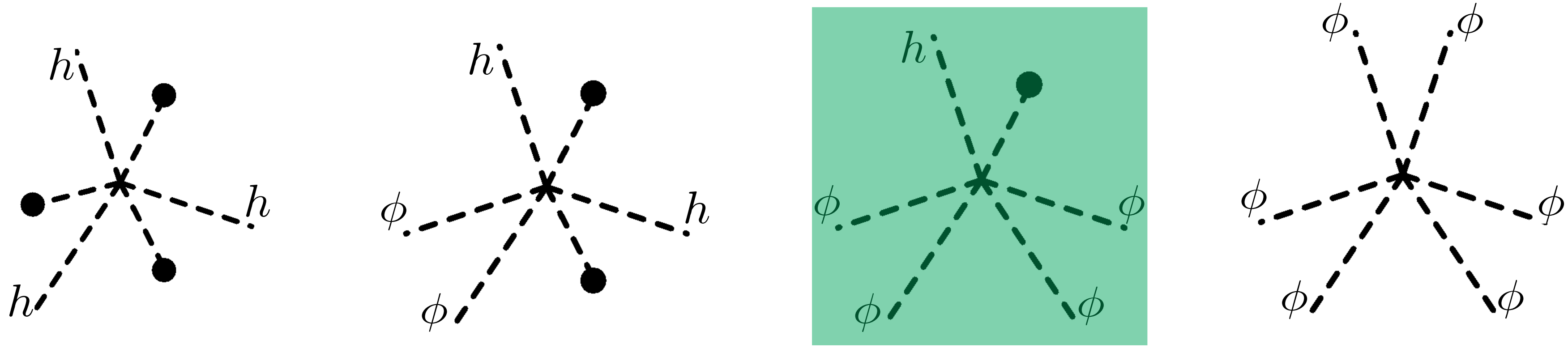
Bishara, Contino, Rojo, '16



No growth with energy, not really competitive with gluon production
Nonetheless, focus of the paper is not in the trilinear

Higgs self-coupling

$$\frac{1}{\Lambda^2}|H|^6 \supset \frac{1}{\Lambda^2}\left(v^3h^3 + 3v^2h^2\phi^2 + 3vh\phi^4 + \phi^6 + \ldots \right)$$



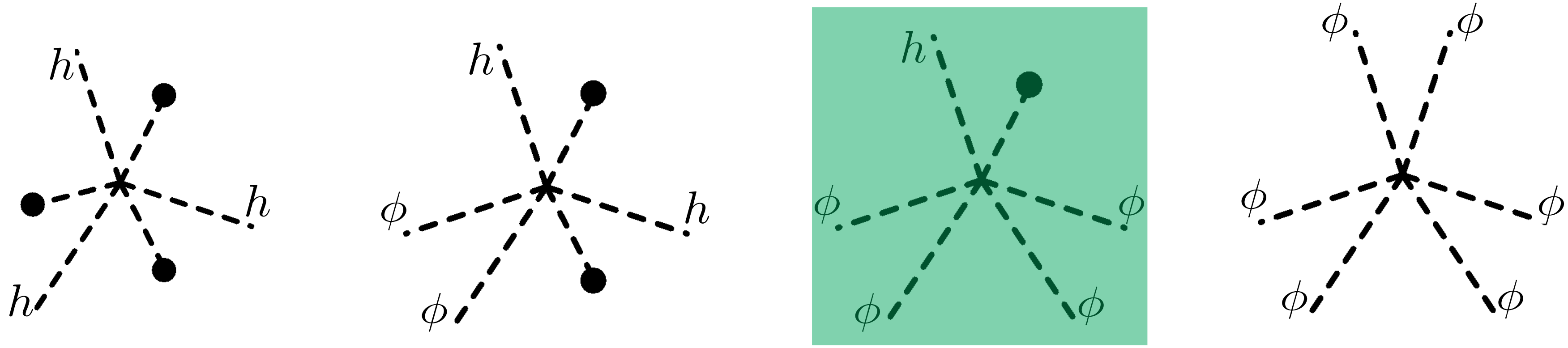
$$\frac{\mathcal{A}(\phi^+\phi^-\phi^+\phi^-h)}{\mathcal{A}(\phi^+\phi^-\phi^+\phi^-h)_{SM}} \sim \frac{c_6 v/\Lambda^2}{v/E^2} \sim c_6\frac{E^2}{\Lambda^2}$$

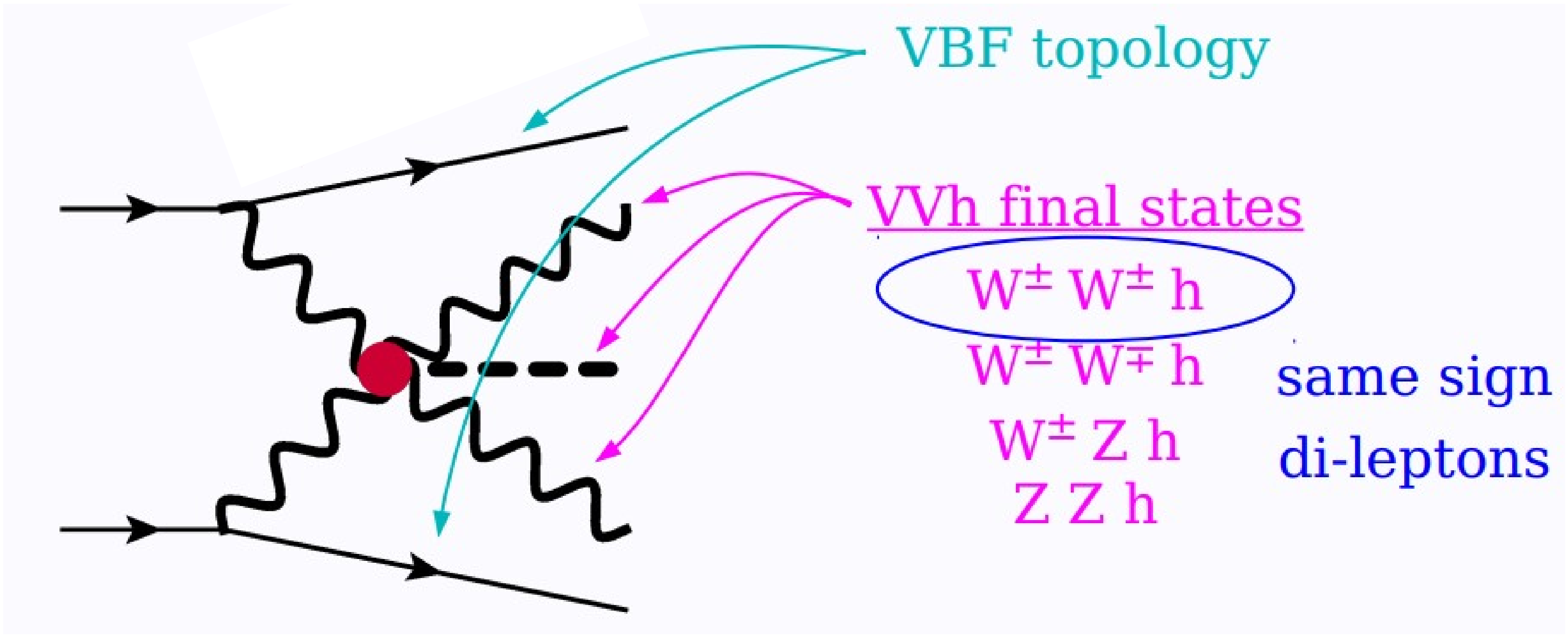
but,

$$\frac{\mathcal{A}(\phi^+\phi^-\phi^+\phi^-h)}{\mathcal{A}(W_T^+W_T^-W_T^+\phi^-h)_{SM}} \sim \frac{c_6 v/\Lambda^2}{p\cdot\epsilon/E^2} \sim c_6\frac{vE}{\Lambda^2}$$

Transverse modes scale as 1/E and become an important background

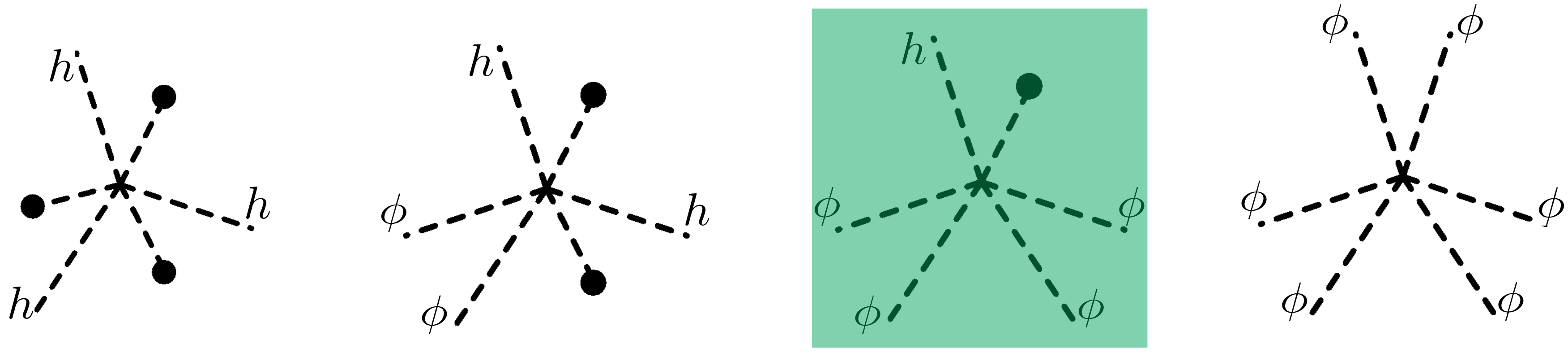
$$\frac{1}{\Lambda^2}|H|^6 \supset \frac{1}{\Lambda^2}\left(v^3h^3 + 3v^2h^2\phi^2 + 3vh\phi^4 + \phi^6 + \ldots\right)$$





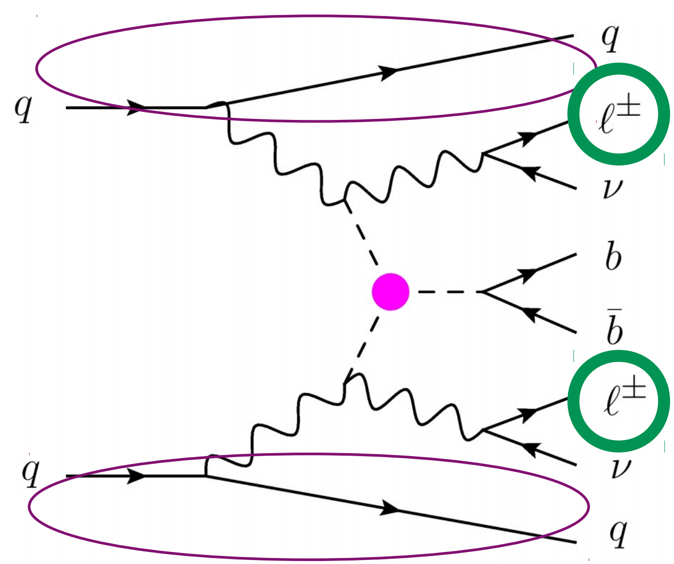
Higgs self-coupling

$$\frac{1}{\Lambda^2}|H|^6 \supset \frac{1}{\Lambda^2}\left(v^3h^3 + 3v^2h^2\phi^2 + 3vh\phi^4 + \phi^6 + \dots\right)$$



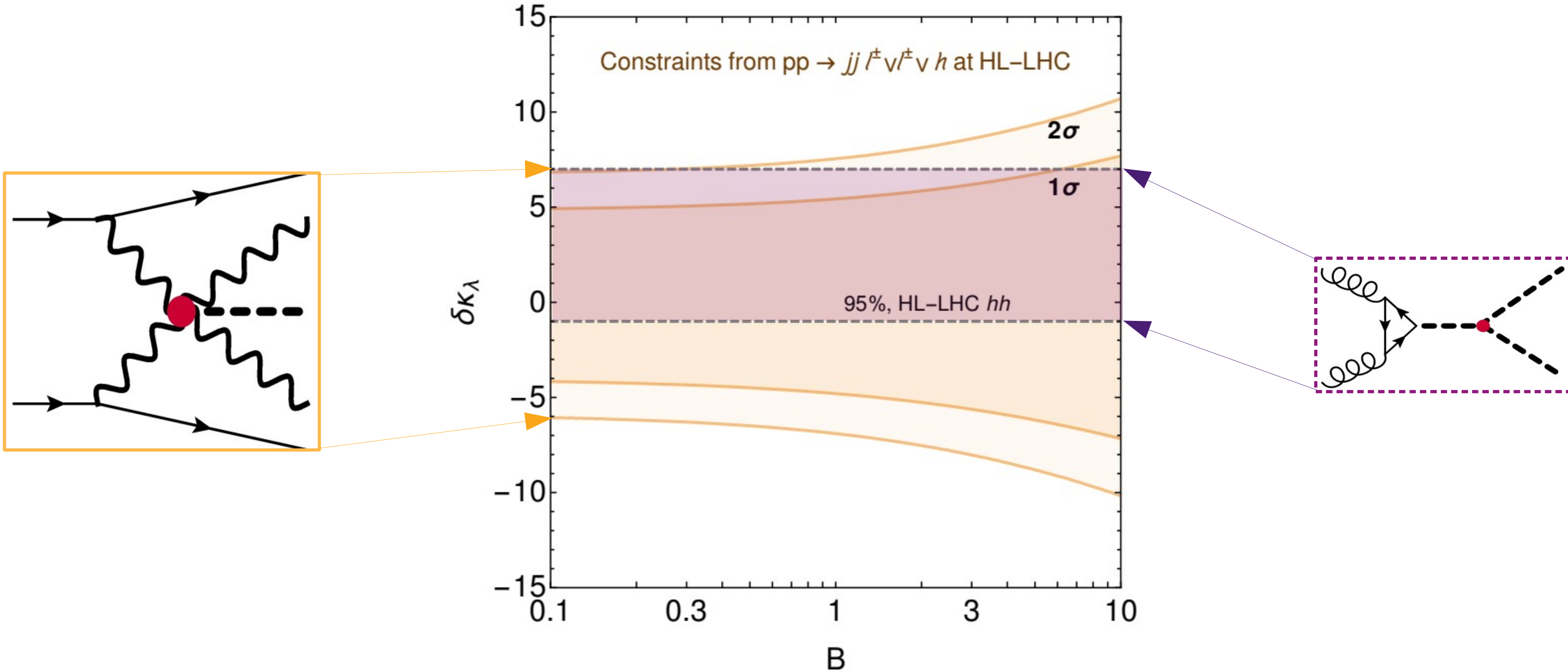
Signal enhanced only with a single power of energy,
but extremelly attractive and clean process experimentally!

VBF topology



Same sign leptons!

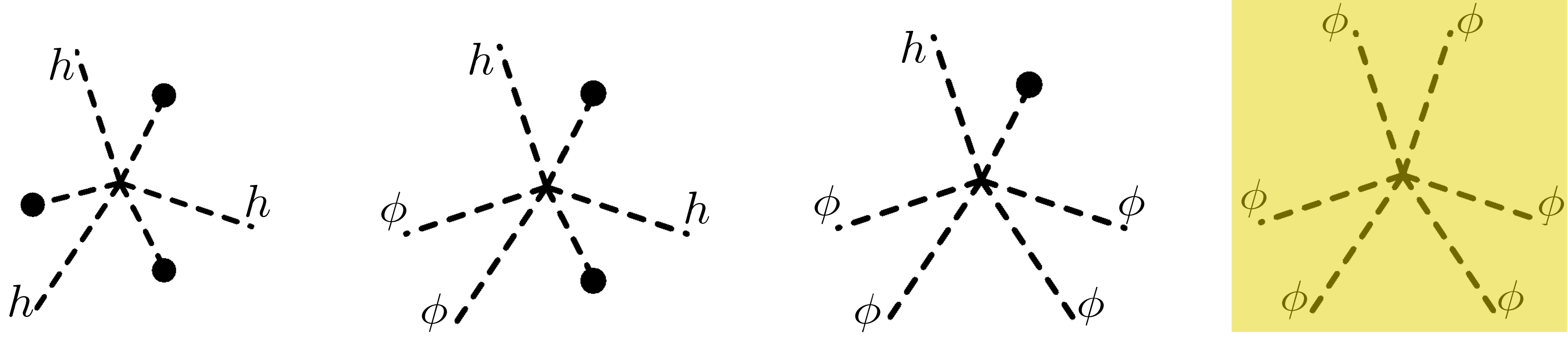
Higgs self-coupling



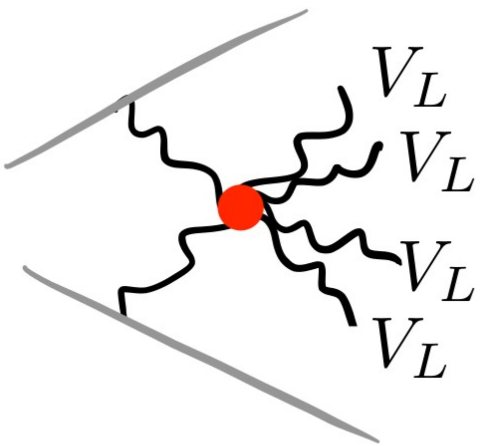
- 50-ish events in the SM
- Irreducible background negligible
- Background from ttjj with lepton misidentification under control
- Backgorund from fake leptons is potentially the dominant one.
  We parametrize it with #back = B x #signal.
- Rough cut-and-count analysis gives competitive results with double higgs production

Higgs self-coupling

$$\frac{1}{\Lambda^2}|H|^6 \supset \frac{1}{\Lambda^2}\left(v^3h^3 + 3v^2h^2\phi^2 + 3vh\phi^4 + \phi^6 + \dots\right)$$



(In progress w/ experimental group in U. Geneve)



$$\delta\mathcal{A}/\mathcal{A} \sim E^2/\Lambda^2$$

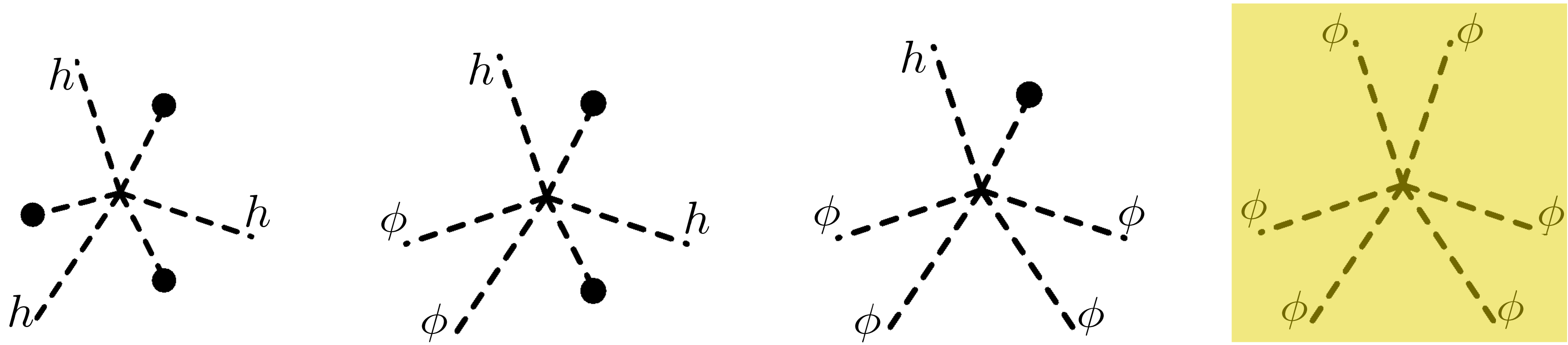
final state

W^+	W^+	W^+	W^+	W^+	W^+	W^+	W^-	W^+	W^-	Z
W^-	W^-	W^-	W^-	W^-	W^-	W^+	W^-	Z	Z	Z
W^+	W^+	W^-	Z	W^+	W^-	Z	Z	Z	Z	Z
W^-	Z	Z	Z	W^+	W^-	Z	Z	Z	Z	Z

```
MG5_aMC>define pm = u u~ d d~
MG5_aMC>generate pm pm > pm pm w+ w- w+ w- QCD=0
Total: 12 processes with 118182 diagrams
Generated helas calls for 12 subprocesses (118182 diagrams) in 379.720 s
Wrote files for 127986 helas calls in 4715.227 s
```

Higgs self-coupling

$$\frac{1}{\Lambda^2}|H|^6 \supset \frac{1}{\Lambda^2}\left(v^3h^3 + 3v^2h^2\phi^2 + 3vh\phi^4 + \phi^6 + \dots \right)$$



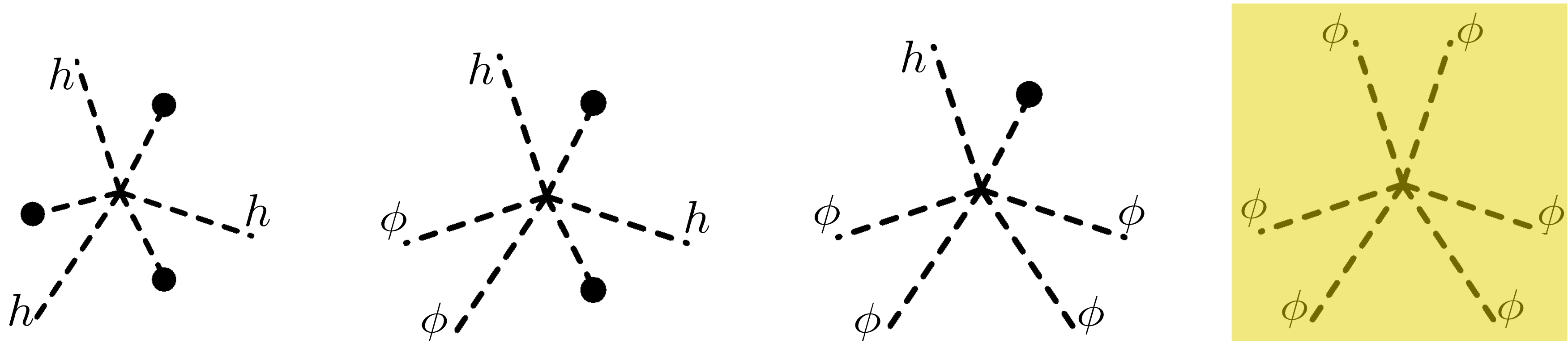
Partonic COM @ 2 TeV:

$$\sigma(W^+W^- \to W^+W^-W^+W^-) \sim 2pb + 2fb\,\delta\kappa_\lambda + 10fb\,\delta\kappa_\lambda^2$$

$$\sigma(ZZ \to ZZZZ) \sim 0.2fb + 1\text{fb}\,\delta\kappa_\lambda + 8\text{fb}\,\delta\kappa_\lambda^2$$

Higgs self-coupling

$$\frac{1}{\Lambda^2}|H|^6 \supset \frac{1}{\Lambda^2}(v^3h^3 + 3v^2h^2\phi^2 + 3vh\phi^4 + \phi^6 + \dots)$$



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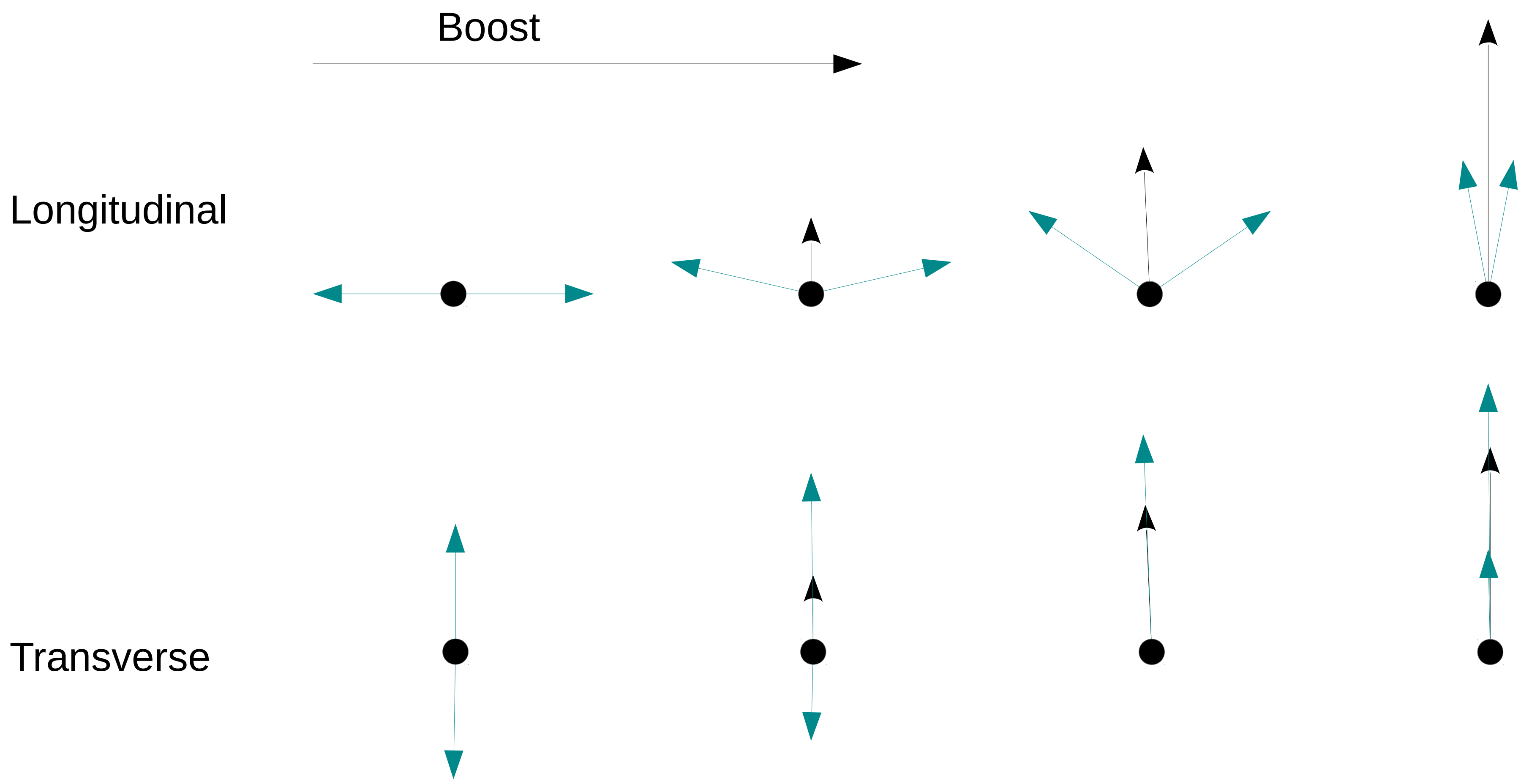
$$\sigma(ZZ \to ZZZZ) \sim 0.2fb + 1\text{fb}\,\delta\kappa_\lambda + 8\text{fb}\,\delta\kappa_\lambda^2$$

First process overwhelmed by transverse modes

Similar sensitivity

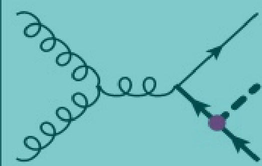
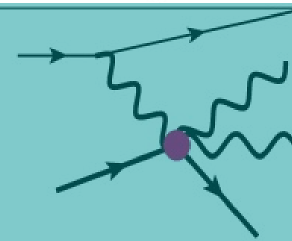
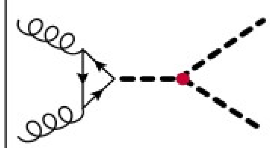
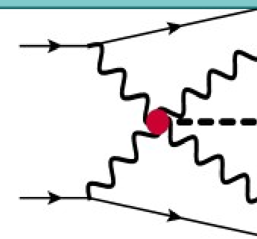
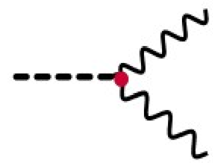
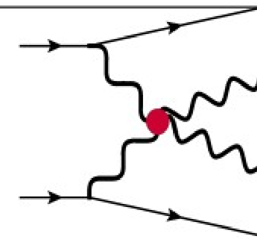
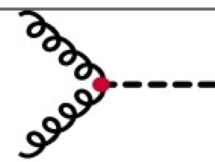
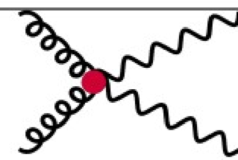
slide from Steven Schramm

Direction of decay products correlated with vector pT and polarization



Angle and energy of two last steps of anti-kT algorithm sensitive to vector polarization!

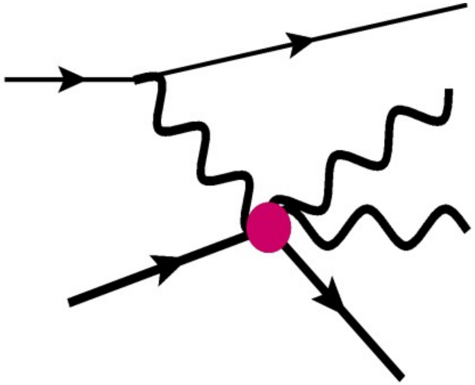
Top Yukawa

		HC	HwH	Growth
κ_t	$\mathcal{O}_{y_t}$			$\sim \frac{E^2}{\Lambda^2}$
κ_λ	$\mathcal{O}_6$			$\sim \frac{vE}{\Lambda^2}$
$\kappa_{Z\gamma}$ $\kappa_{\gamma\gamma}$ κ_V	$\mathcal{O}_{WW}$ $\mathcal{O}_{BB}$ $\mathcal{O}_r$			$\sim \frac{E^2}{\Lambda^2}$
κ_g	$\mathcal{O}_{gg}$			$\sim \frac{E^2}{\Lambda^2}$

Top Yukawa

$$\mathcal{L} \supset \frac{c_t}{\Lambda^2} y_t |H|^2 \bar{q}_L H t_R$$

$$\phi^+\phi^- \qquad b_L \phi^+ t_R$$



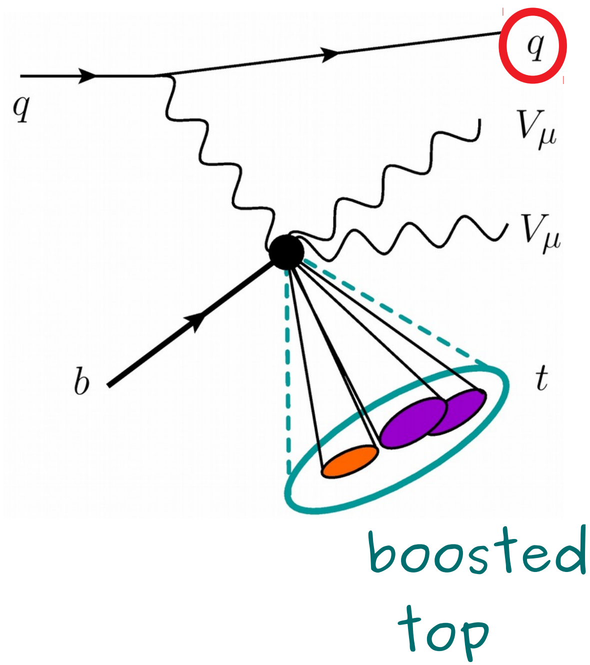
$$\sim \frac{E^2}{\Lambda^2}$$

Many final states, many decays... just if we had something to simplify the analysis...

Top Yukawa

$$\mathcal{L} \supset \frac{c_t}{\Lambda^2} y_t |H|^2 \bar{q}_L H t_R$$

$$\phi^+\phi^- \qquad b_L \phi^+ t_R$$



$|\eta_j| > 2.5, p_T^j > 30\text{GeV}, E_j > 300\text{GeV}$

events @ HL-LHC

Process	0ℓ	1ℓ	$\ell^\pm\ell^\mp$	$\ell^\pm\ell^\pm$	$3\ell(4\ell)$
$W^\pm W^\mp$	3449/567	1724/283	216/35	-	-
$W^\pm W^\pm$	2850/398	1425/199	-	178/25	-
$W^\pm Z$	3860/632	965/158	273/45	-	68/11
ZZ	2484/364	-	351/49	-	(12/2)

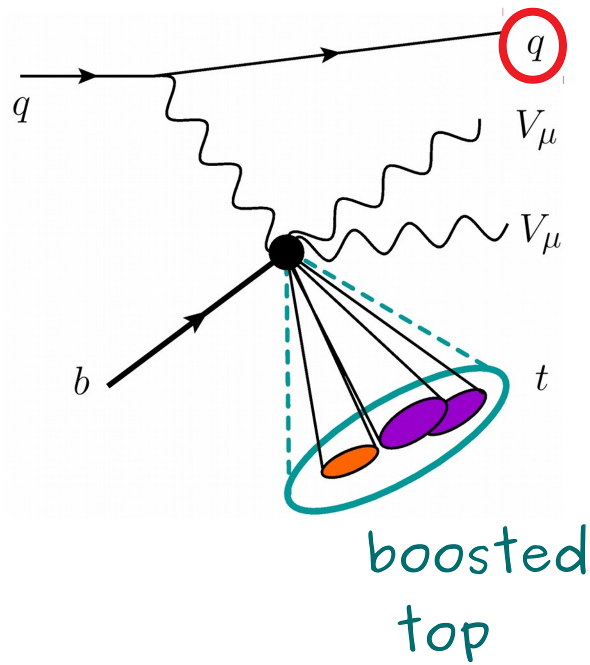
$p_T^t > 250$ GeV / $p_T^t > 500$ GeV

Strategy: look for a single boosted top + forward jet, then just count leptons!

Top Yukawa

$$\mathcal{L} \supset \frac{c_t}{\Lambda^2} y_t |H|^2 \bar{q}_L H t_R$$

$$\phi^+\phi^- \qquad b_L \phi^+ t_R$$



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events @ HL-LHC

Process	0ℓ	1ℓ	$\ell^\pm\ell^\mp$	$\ell^\pm\ell^\pm$	$3\ell(4\ell)$
$W^\pm W^\mp$	3449/567	1724/283	216/35	-	-
$W^\pm W^\pm$	2850/398	1425/199	-	178/25	-
$W^\pm Z$	3860/632	965/158	273/45	-	68/11
ZZ	2484/364	-	351/49	-	(12/2)

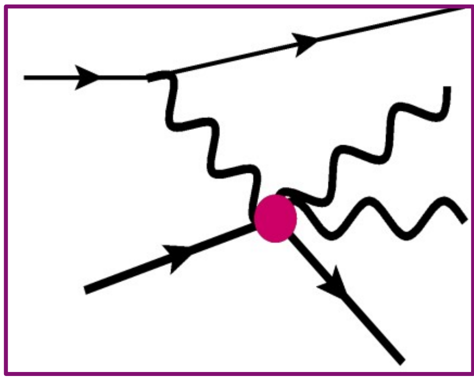
$p_T^t > 250$ GeV / $p_T^t > 500$ GeV

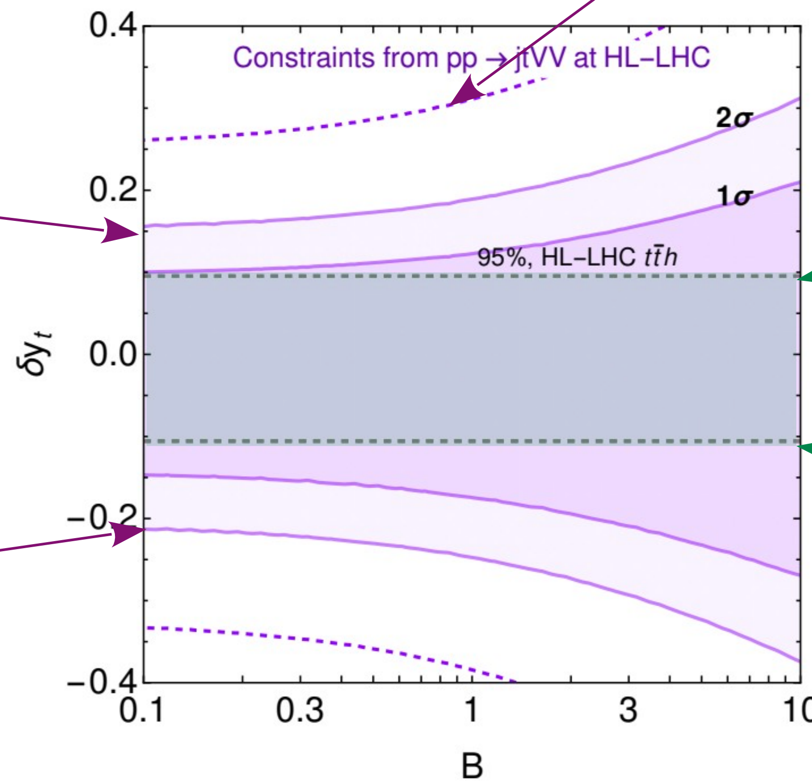
Large background from ttjj, but manageable.
Going to larger top pT's possible

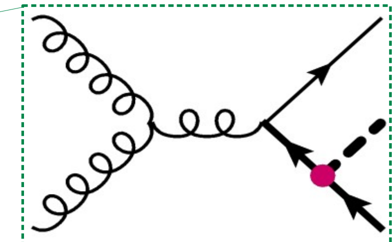
small background

Top Yukawa

>2 leptons only





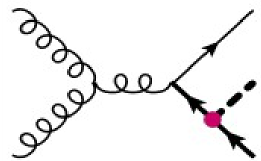
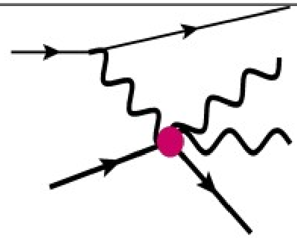
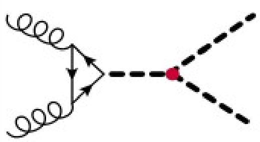
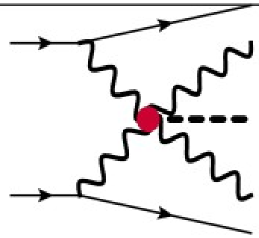
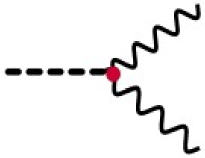
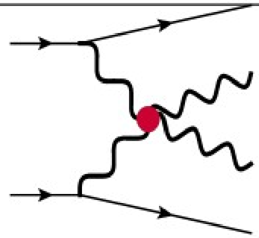
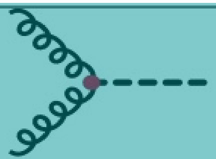
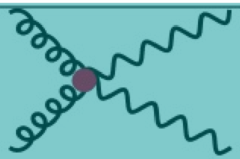


Again, we parametrize background with B x signal

Competitive with on-shell Higgs measurements

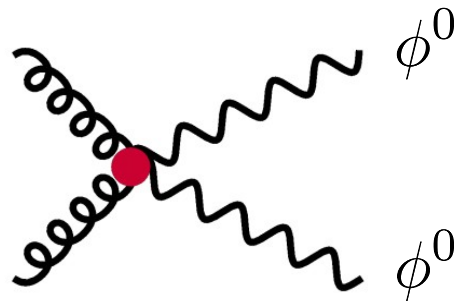
Further improvements: background characterization, specially for hadronic,
differential information, larger E^2,
get rid of transverse polarizations

H to gluons

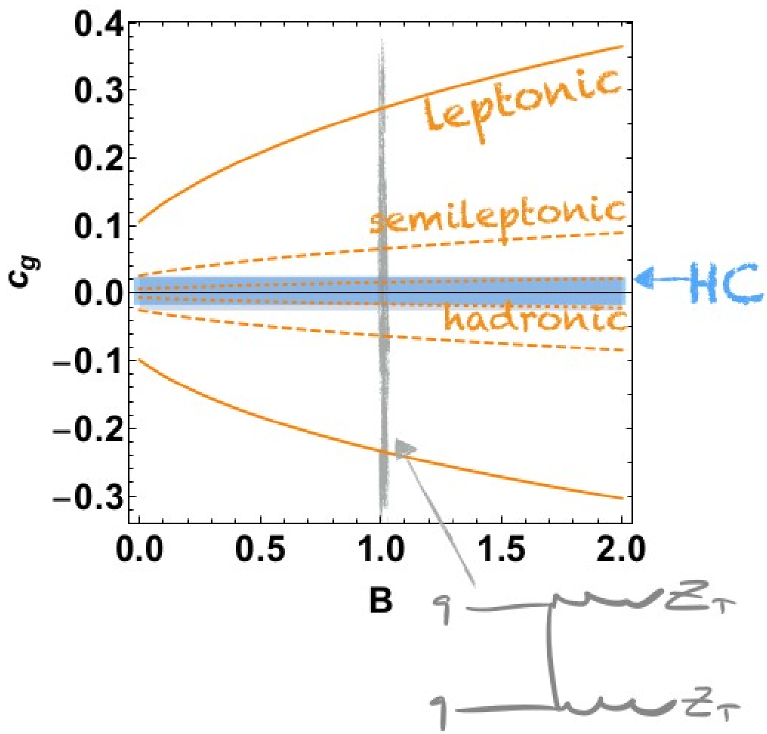
		HC	HwH	Growth
κ_t	$\mathcal{O}_{y_t}$			$\sim \frac{E^2}{\Lambda^2}$
κ_λ	$\mathcal{O}_6$			$\sim \frac{vE}{\Lambda^2}$
$\kappa_{Z\gamma}$ $\kappa_{\gamma\gamma}$ κ_V	$\mathcal{O}_{WW}$ $\mathcal{O}_{BB}$ $\mathcal{O}_r$			$\sim \frac{E^2}{\Lambda^2}$
κ_g	$\mathcal{O}_{gg}$			$\sim \frac{E^2}{\Lambda^2}$

H to gluons

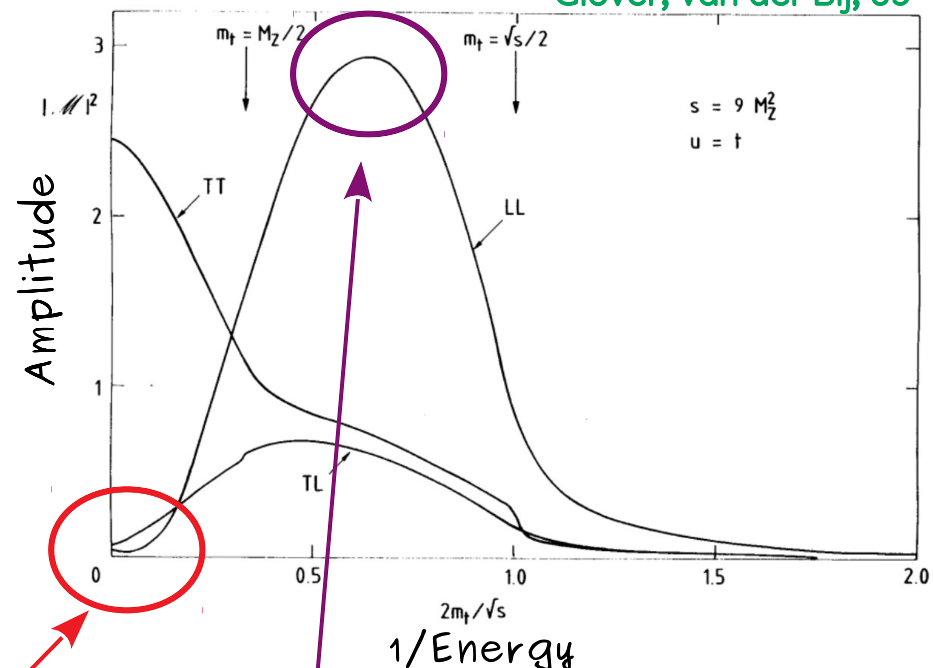
Azatov, Grojean, Paul, Salvioni, '14



Contraints looking only at rates:



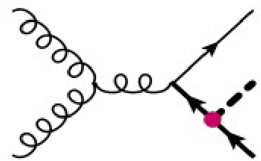
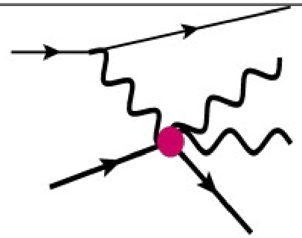
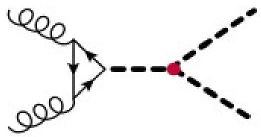
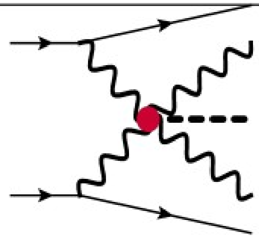
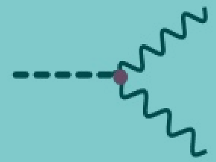
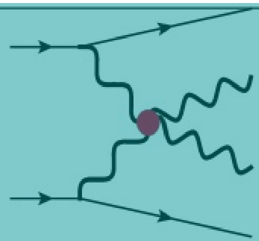
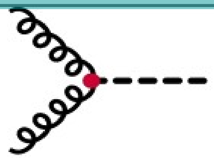
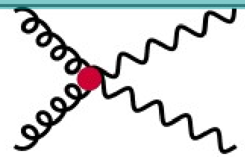
Glover, van der Bij, 89



Production of longitudinal modes goes to zero at high energies (similar to send quarks mass to zero)

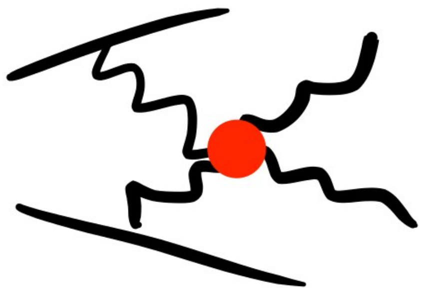
Should be possible to 'sit' at this maximum and dig out the longitudinals to improve constraints & be sensitive to linear terms only

Vector boson scattering

		HC	HwH	Growth
κ_t	$\mathcal{O}_{y_t}$			$\sim \frac{E^2}{\Lambda^2}$
κ_λ	$\mathcal{O}_6$			$\sim \frac{vE}{\Lambda^2}$
$\kappa_{Z\gamma}$ $\kappa_{\gamma\gamma}$ κ_V	$\mathcal{O}_{WW}$ $\mathcal{O}_{BB}$ $\mathcal{O}_r$			$\sim \frac{E^2}{\Lambda^2}$
κ_g	$\mathcal{O}_{gg}$			$\sim \frac{E^2}{\Lambda^2}$

Vector boson scattering

Usually, VBS is interpreted in terms of dimension 8 operators.
But they recieve contributions from Higgs operators



$$|H|^2 W^a_{\mu\nu} W^a_{\mu\nu} \qquad \kappa_{\gamma\gamma} h A_{\mu\nu} A_{\mu\nu}$$

$$|H|^2 B_{\mu\nu} B_{\mu\nu} \qquad \kappa_{Z\gamma} h Z_{\mu\nu} A_{\mu\nu}$$

We project current analysis on W+W+, WZ, ZZ and Zγ

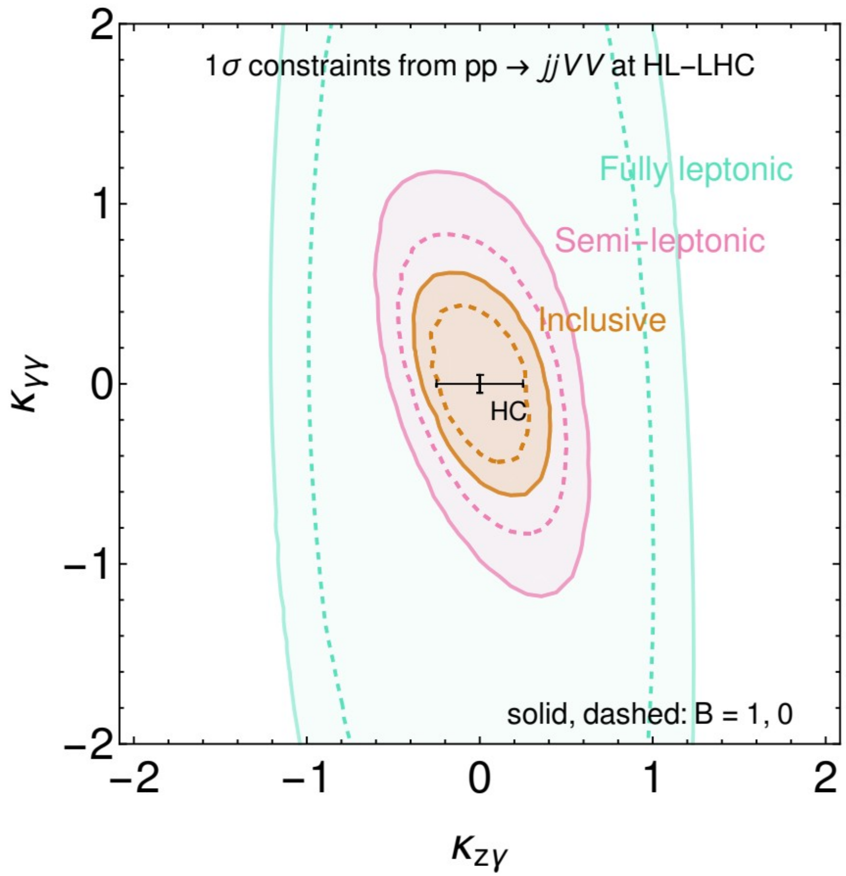
e.g., ATLAS, 1405.6241
ATLAS, 1705.01966

Hardness of 2→2 characterized by scalar sum of vectors' pT, we bin on it.

Other channels, W+W−, W+γ, γγ are left for future study.

VBS with VH final state is not studied so far, but it might be comparably sensitive.

Vector boson scattering



- Competitive for Zγ, not for γγ
- If VBS with W+fat jet, W+W− will also enter
- VBF of VH to be studied

Conclusions

Conclusions

- Characterization of Higgs is crucial
- High energy Higgs probes competitive and complementary to HC measurements
- Important for future high energy colliders, HE-LHC, CLIC, FCC/SppC
- Endless oportunities for improvements:
  - Precise theoretical predictions
  - Understanding of relevant kinematics
  - Even more primitive: understanding of relevant processes
  - Experimental control of systematics and backgrounds
  - Understanding of longitudinal vs transverse gauge bosons
  - BSM interpretation
  - ...
- Plenty of relevant physics yet to be explored