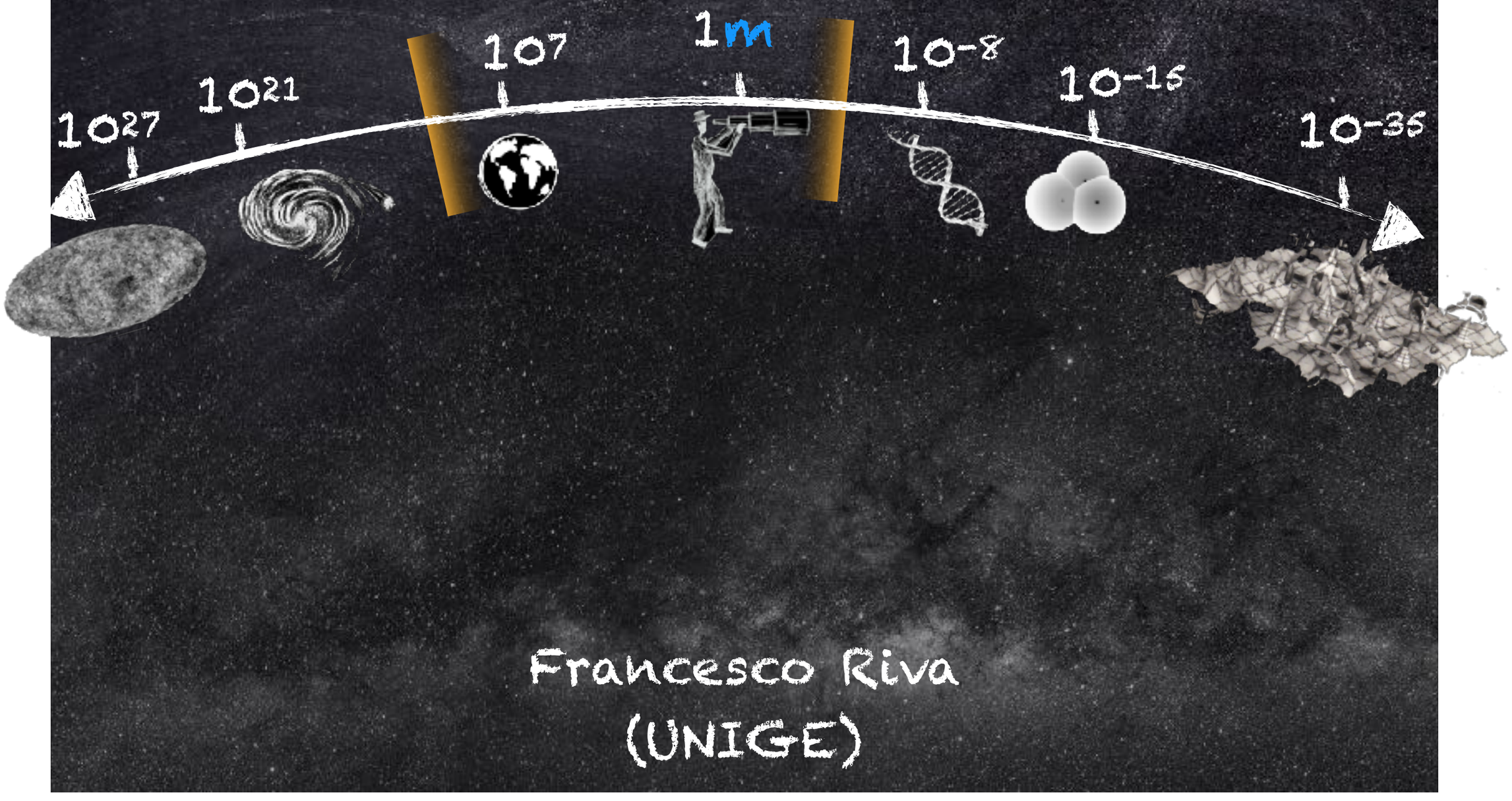
Higgs Couplings ... without the Higgs

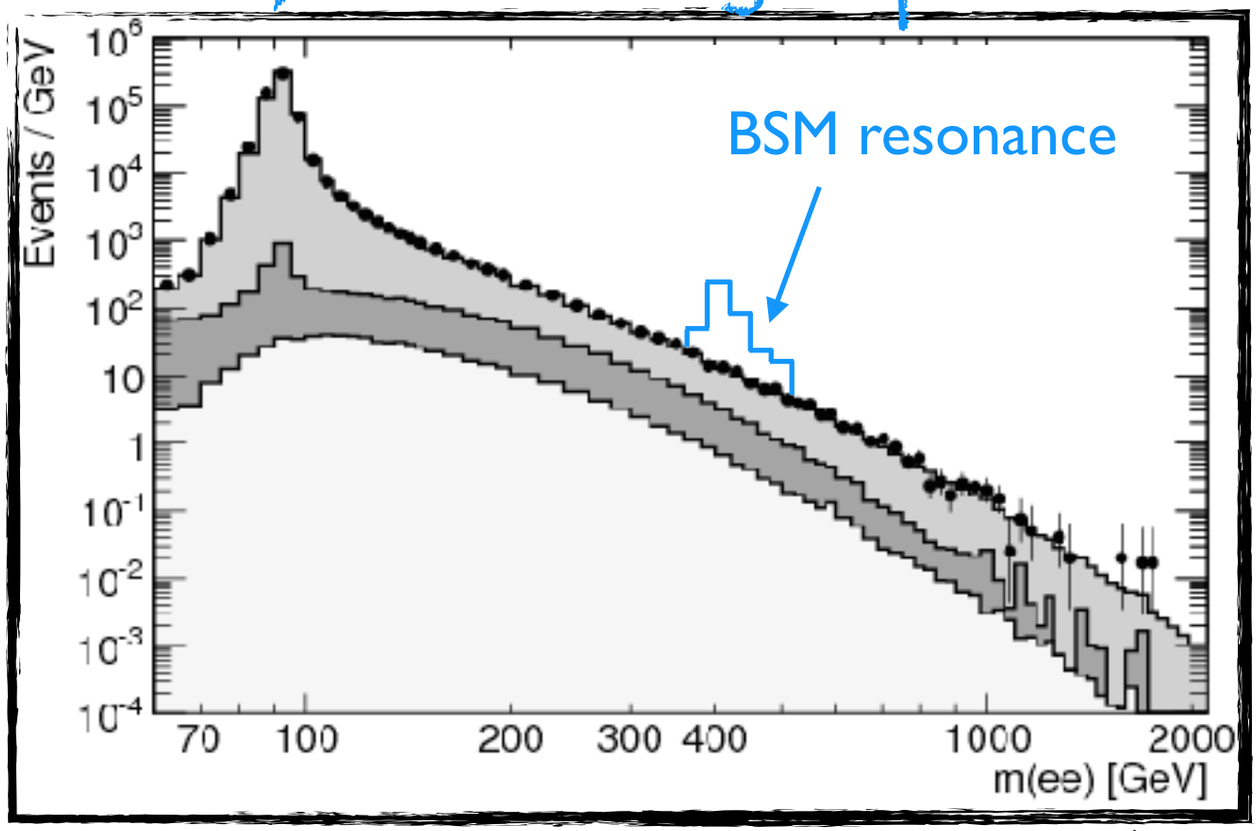


Francesco Riva
(UNIGE)

In collaboration with
Henning, Lombardo, Riembau
arXiv: 1812.09299

Collider Exploration

Focus so far: Search for new light particles



Energy frontier (13 TeV)

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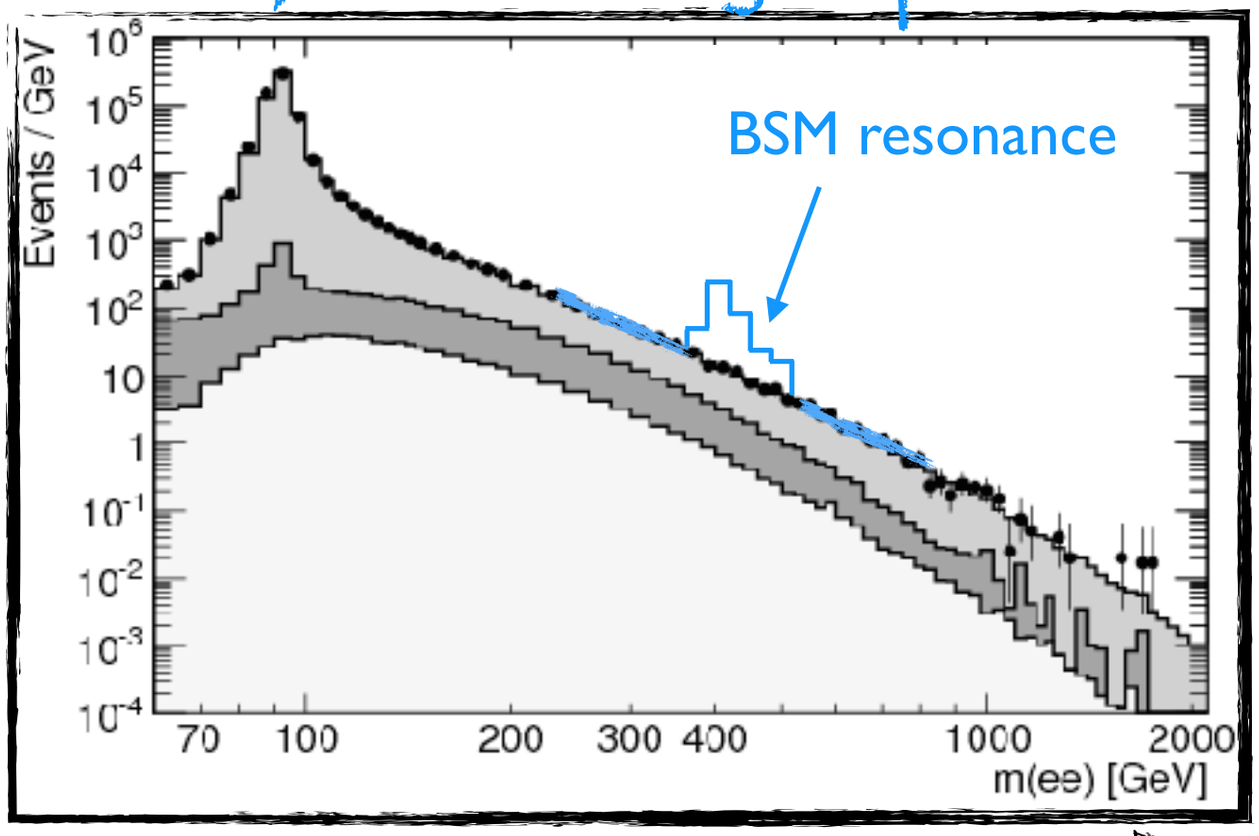


Energy frontier (13 TeV)

- Experimentally: First accessible signal/Easy to study

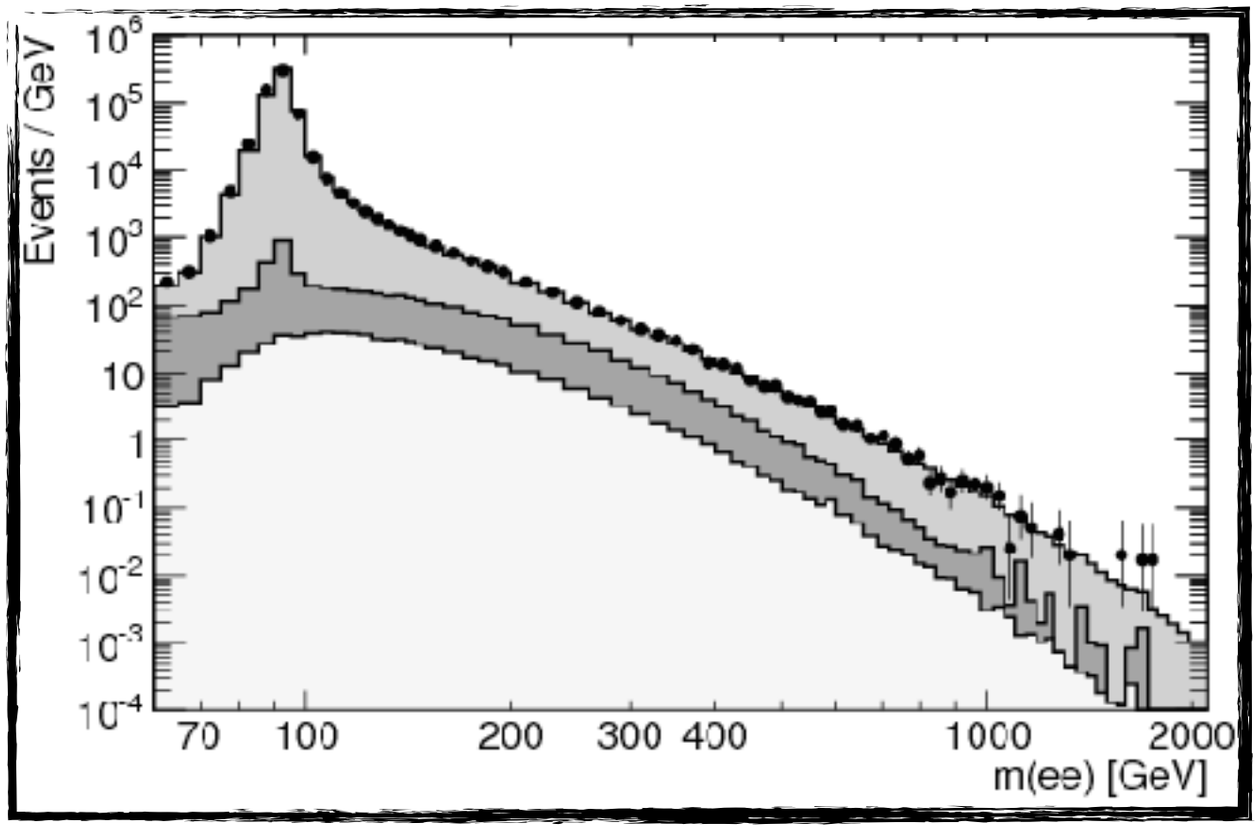
Collider Exploration

Focus now: Standard Model Precision Tests

(2035: 3000 fb^{-1})

intensity frontier

(2019: 65 fb^{-1})



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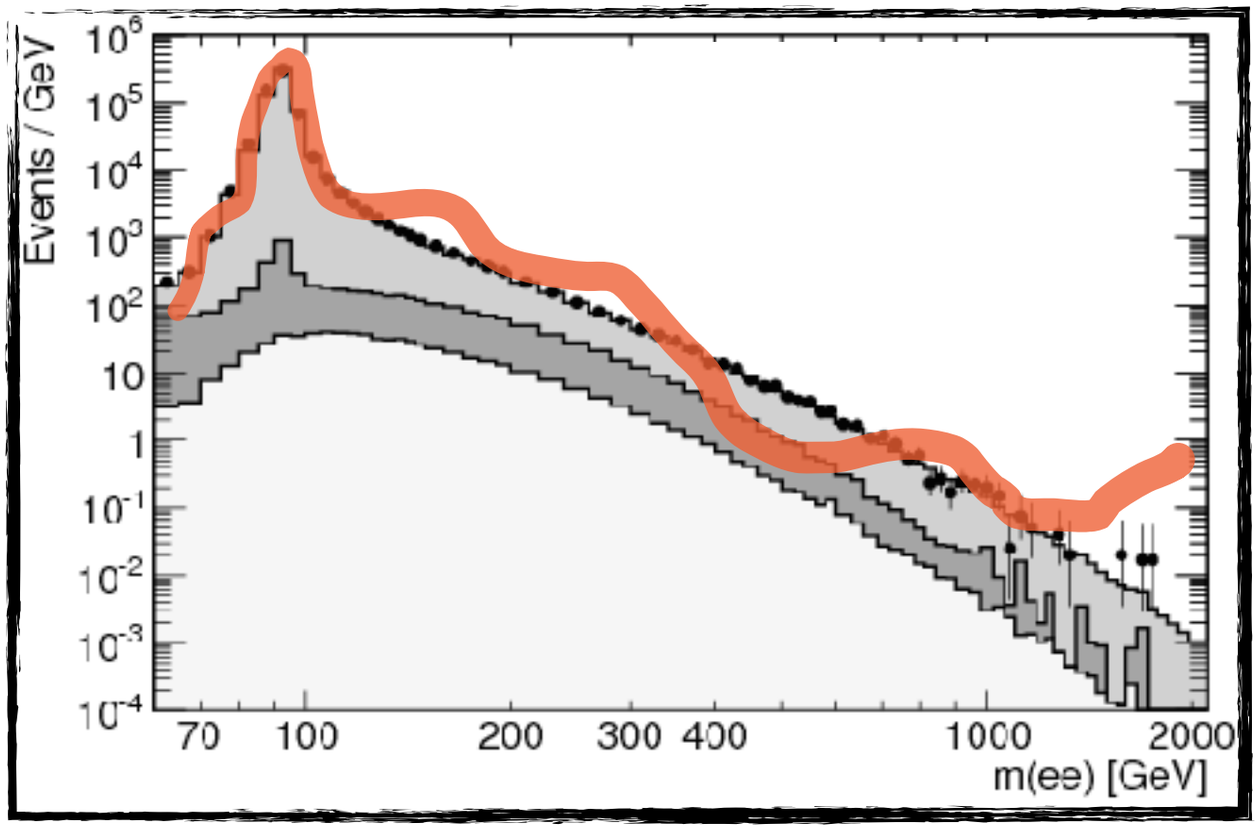

Infinite Information

$$function(E^2) = f(0) + f'(0)E^2 + f''(0)E^4 + \cdots$$

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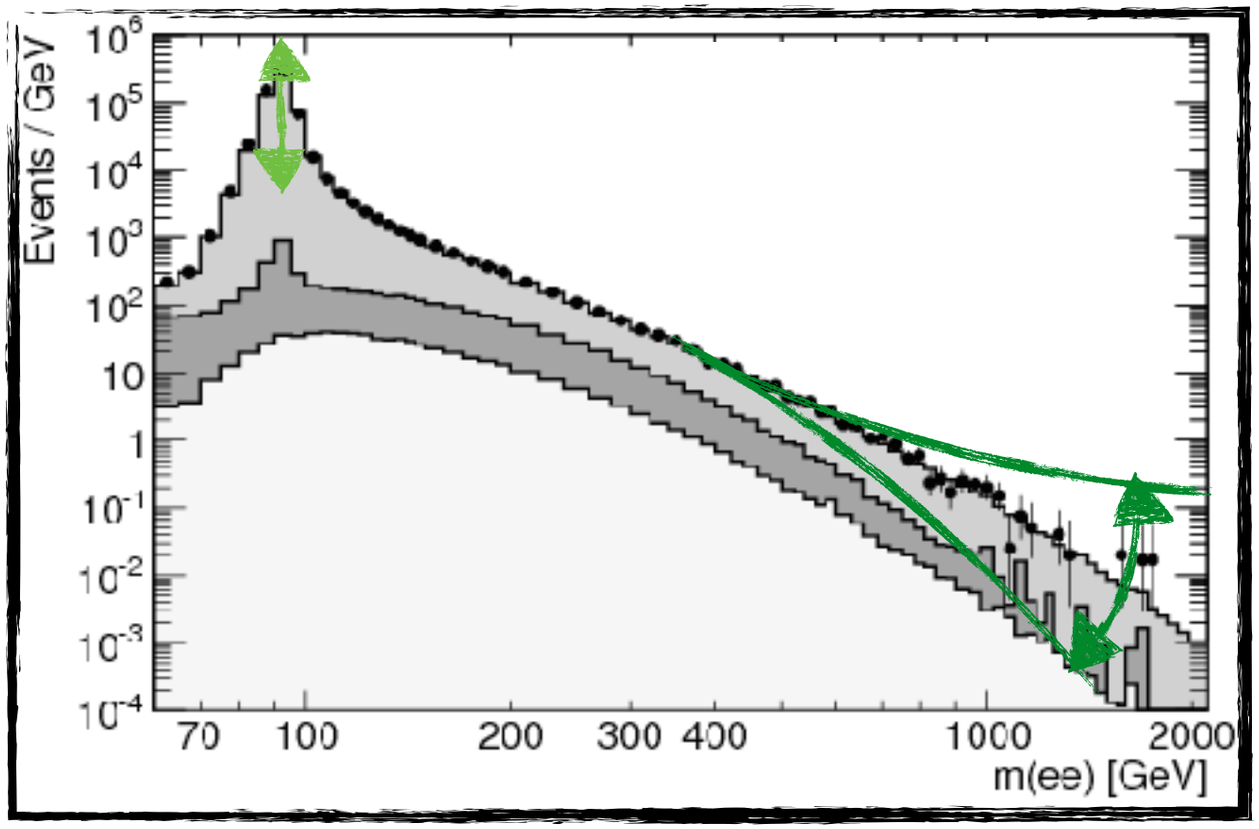

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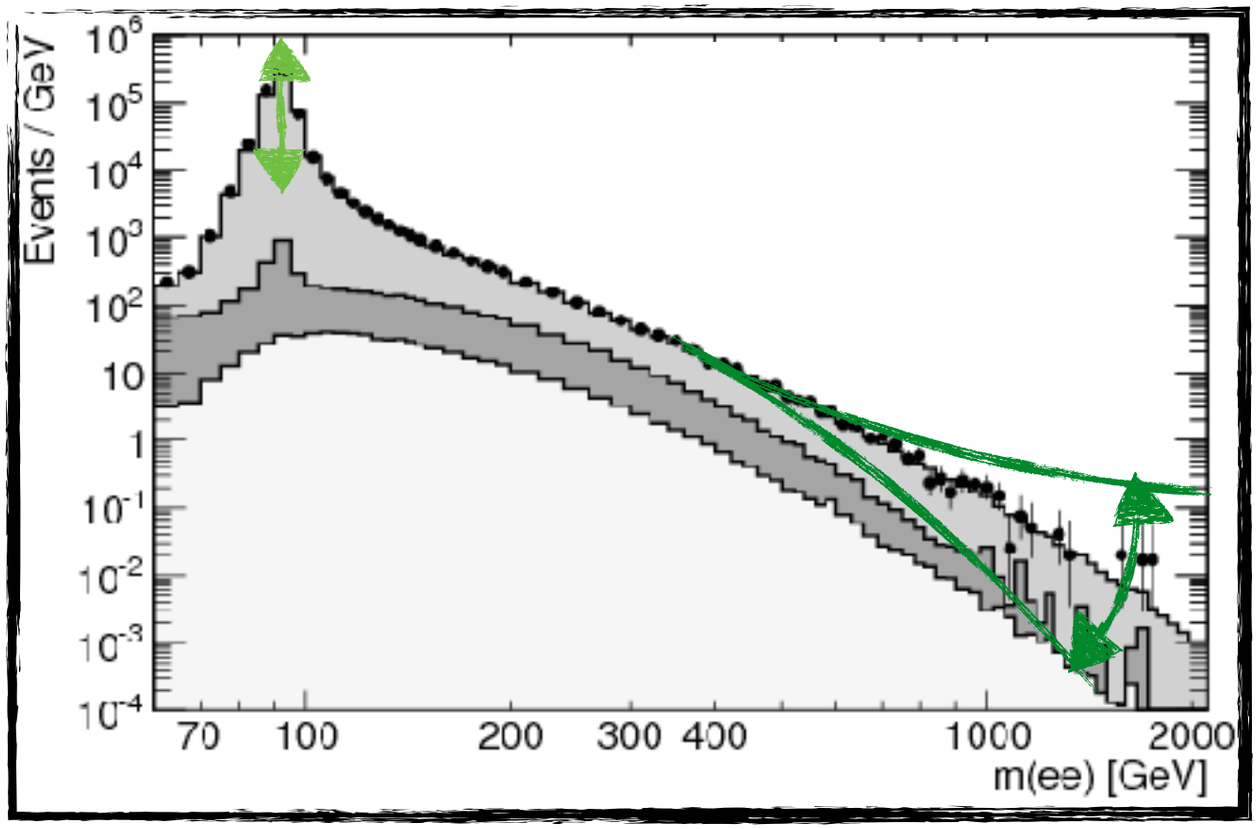

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systematic Taylor expansion for **all** observables

Effective Field Theory (EFT)

$$\mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{SM}} + \frac{1}{\Lambda^2}\sum_i c_i \mathcal{O}_i + \cdots$$

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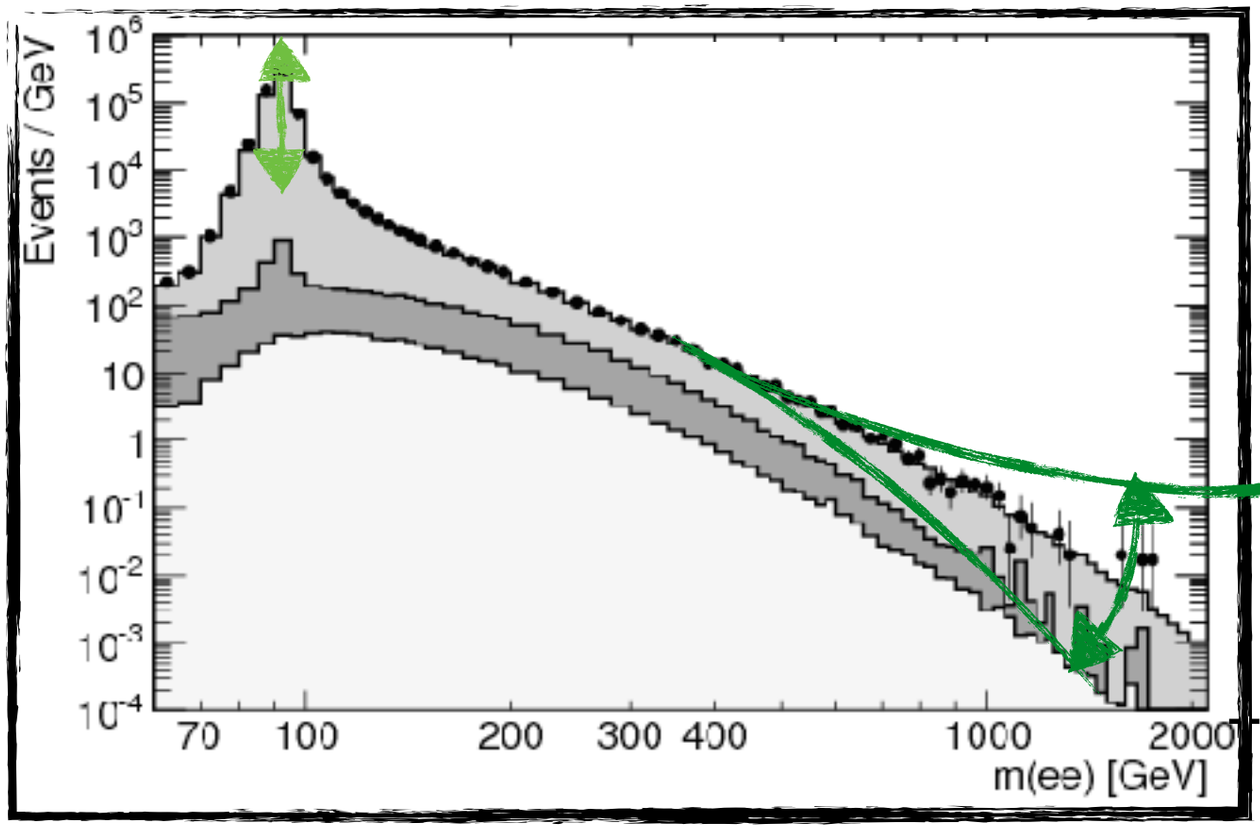

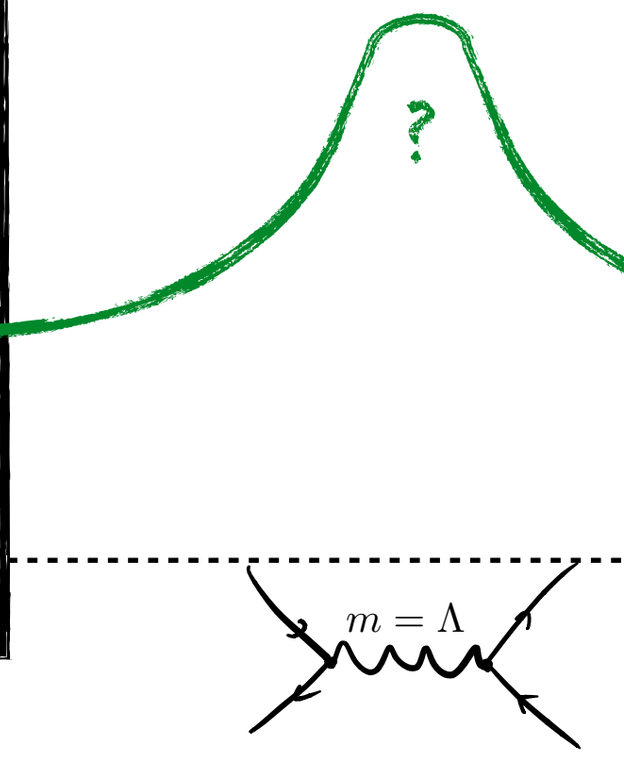

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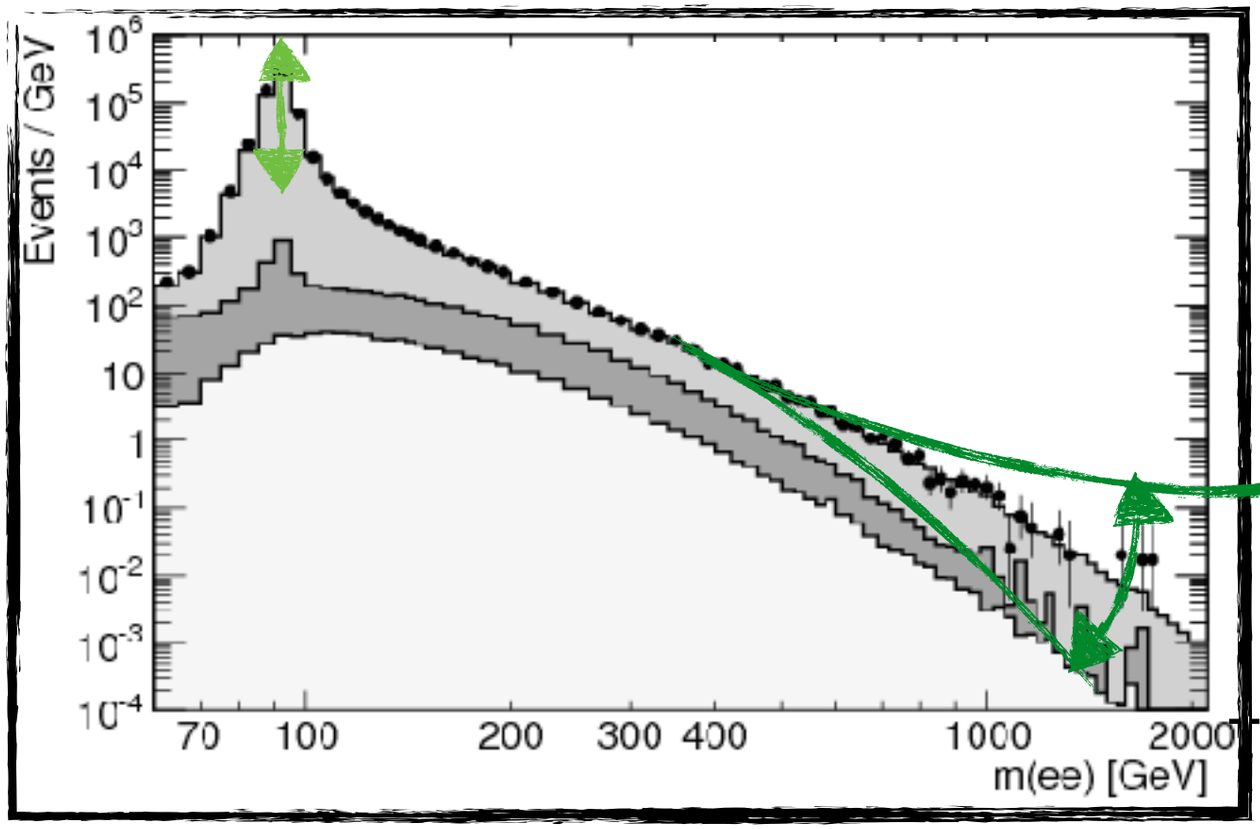

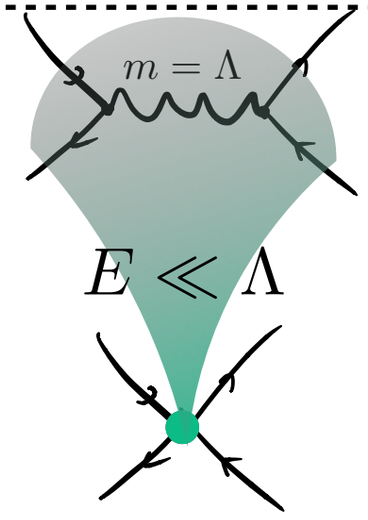

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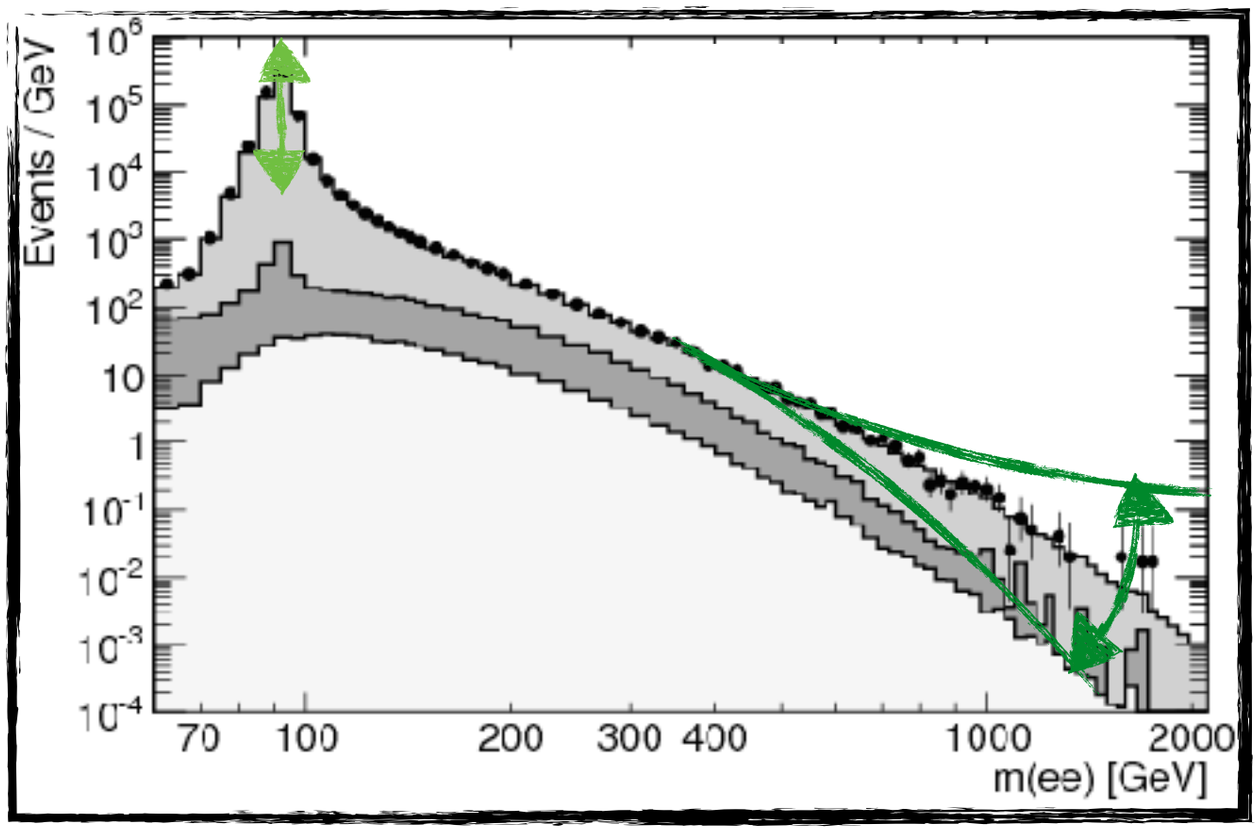
$$\mathcal{O}_i = \frac{(\bar{\psi}\gamma_\mu\psi)^2}{\Lambda^2}$$

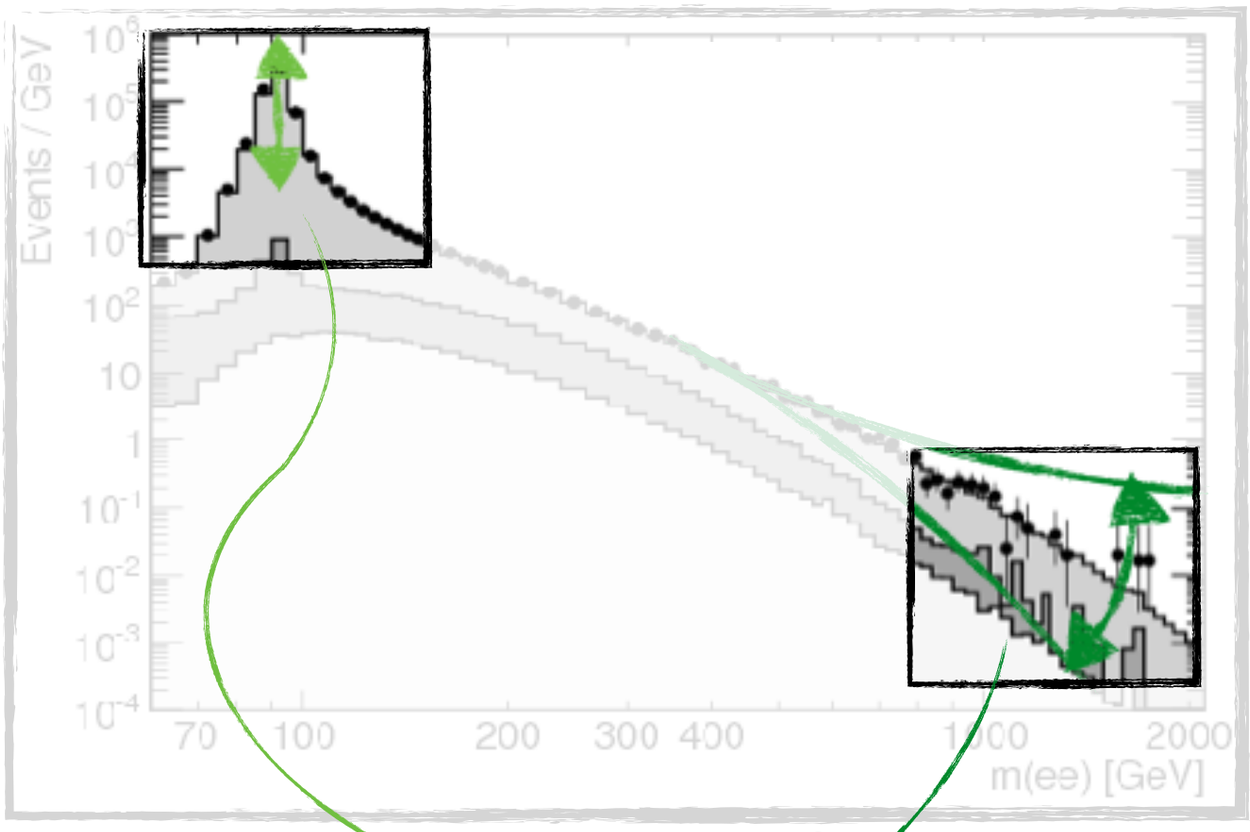
most relevant effects from all heavy BSM

Precision Tests



$$\sigma = \sigma_{\rm SM}\left(1 + c\frac{E^2}{\Lambda^2} + \cdots\right)$$

Precision Tests



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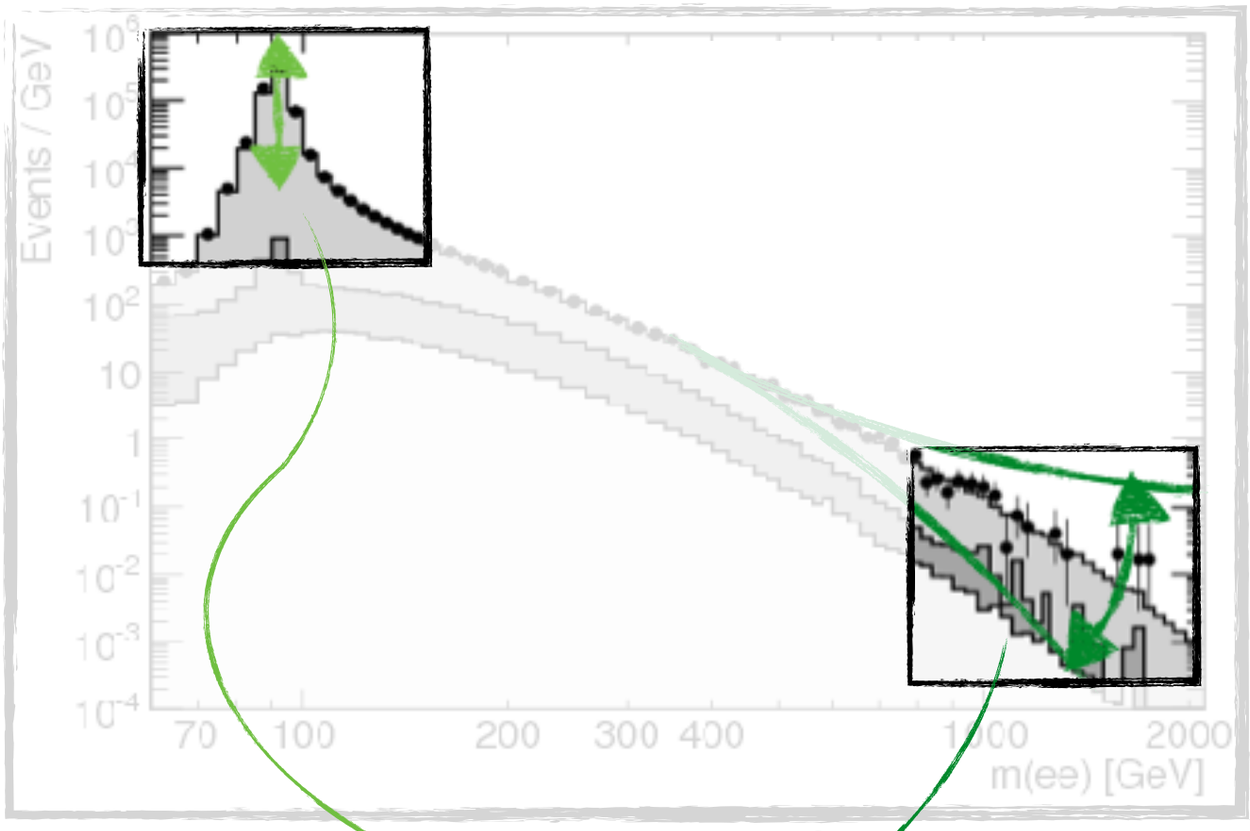
Precision Tests

e.g. Z-pole, Higgs Couplings,...

- big statistics
- systematic limited



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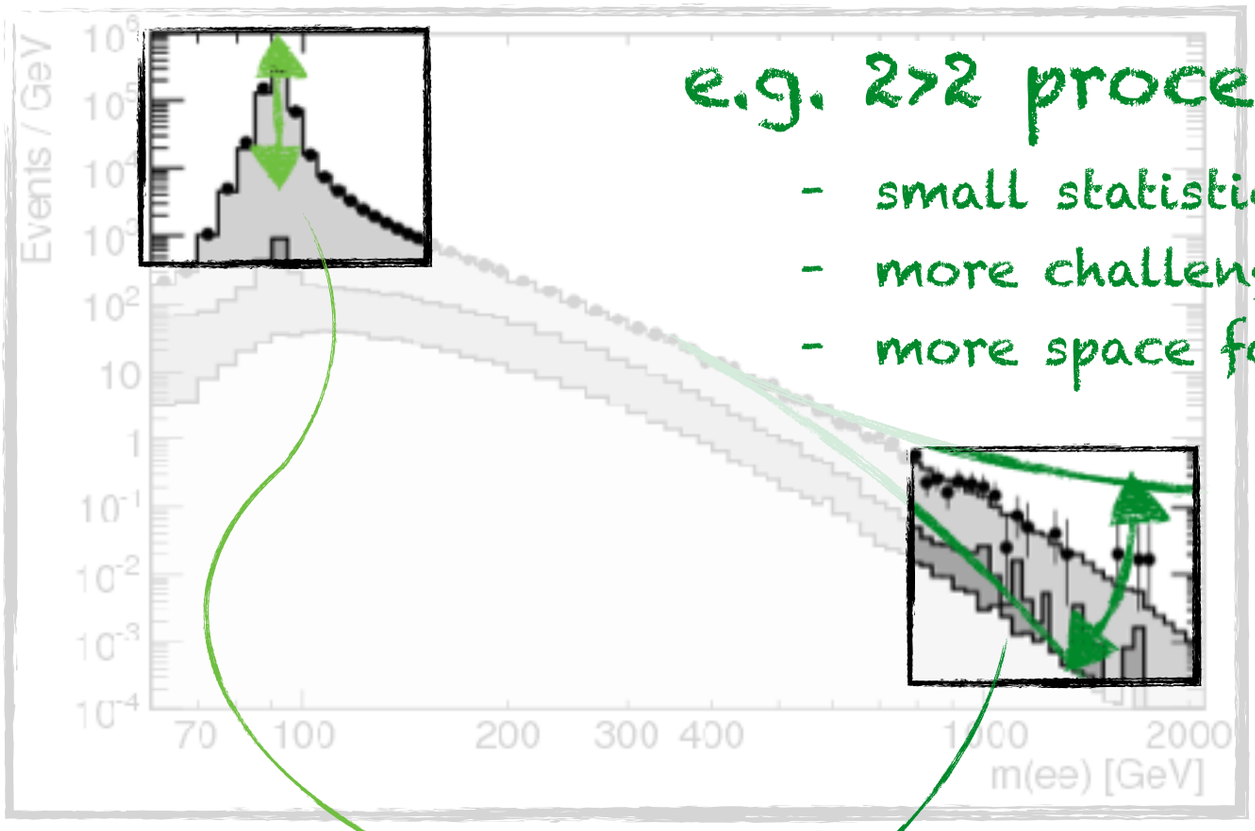

e.g. 2>2 processes, ZH, WW,...

- small statistics
- more challenging measurement
- more space for improvement

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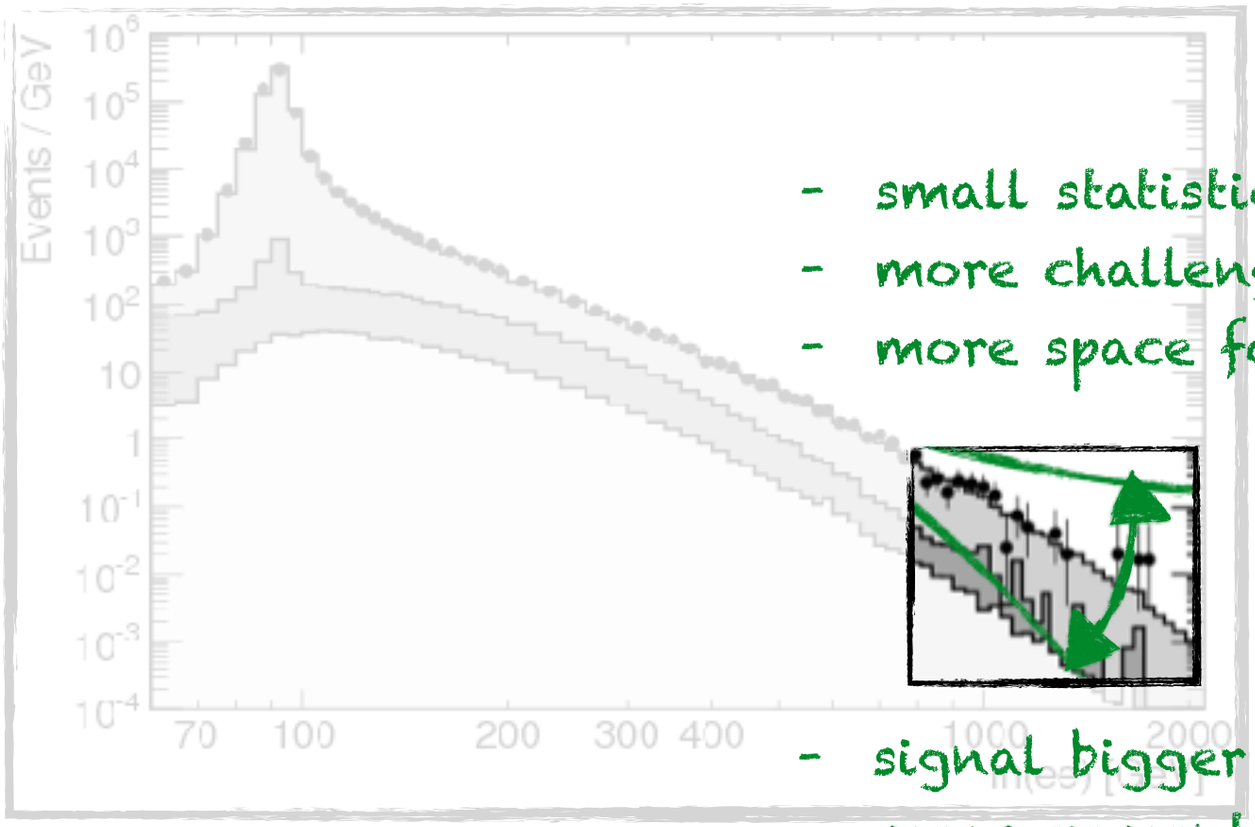
Precision Tests



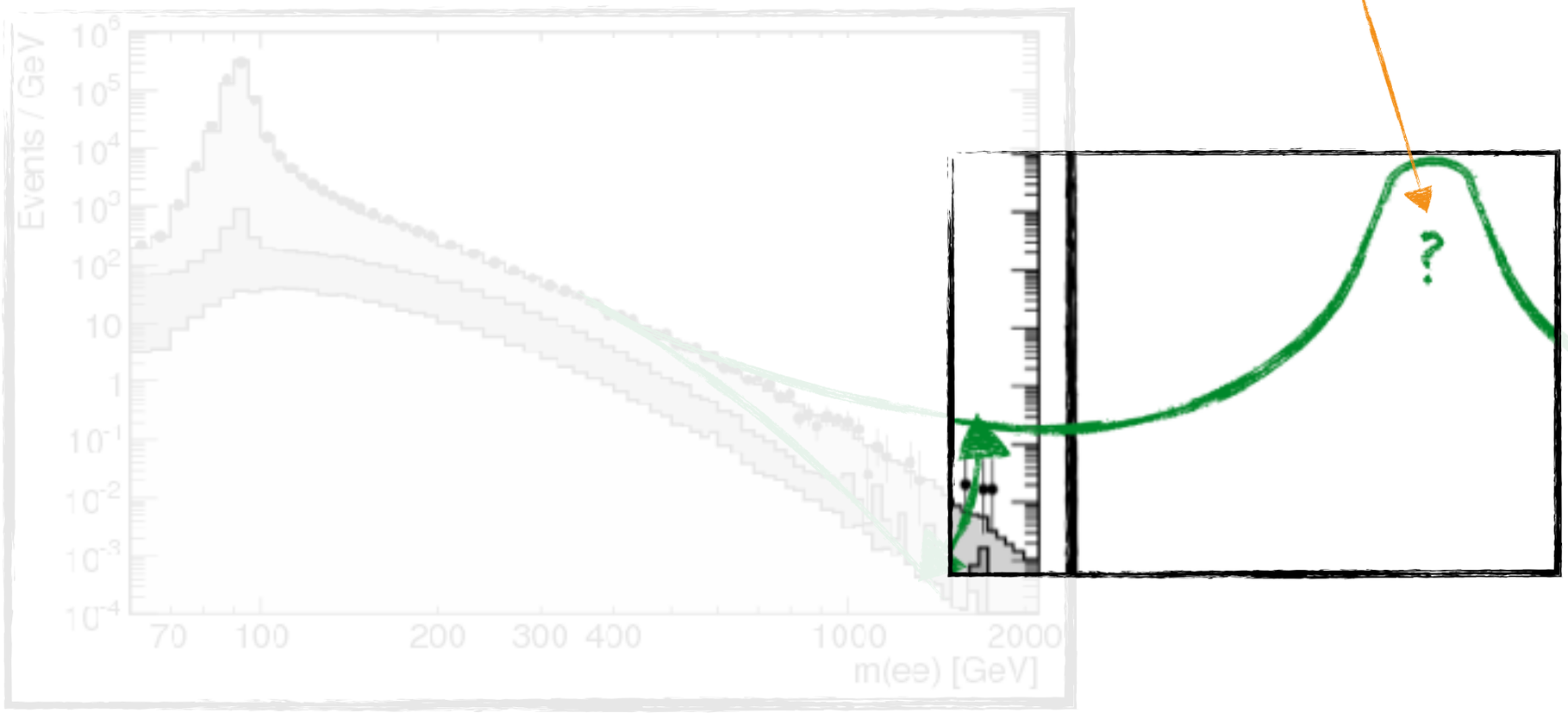
- small statistics
- more challenging measurement
- more space for improvement

- signal bigger (even a poorer measurement can be precise)

$$\frac{E^2_{max}}{m^2_Z} = \left(\frac{360}{91}\right)^2 \approx 15$$

BSM Perspective

What do we expect from a theory point of view?



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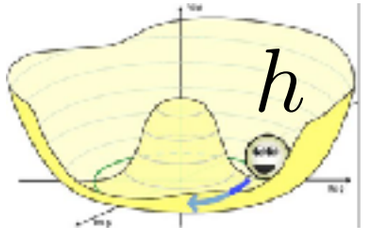
Composite Higgs Models: Higgs is a (pseudo) goldstone boson

(it's natural, because a Pion is natural)



Giudice,Grojean,Pomarol,Rattazzi'08;
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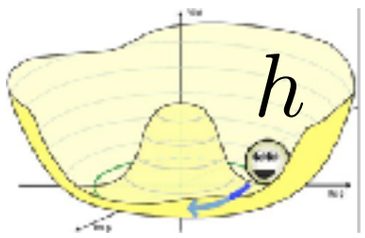

SM		BSM
h	$\longrightarrow$	$\sin h \;\; = (h - \frac{h^3}{3!} + \cdots)$
$\bar{\psi}\psi\, h$		$\bar{\psi}\psi\, h \;\; + c\, \bar{\psi}\psi h^3$

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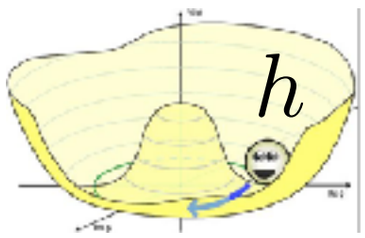

SM **BSM**

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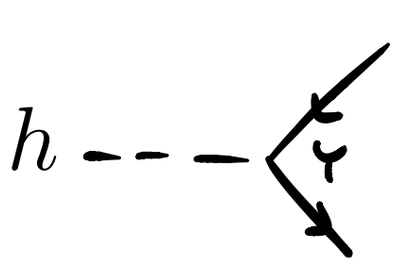

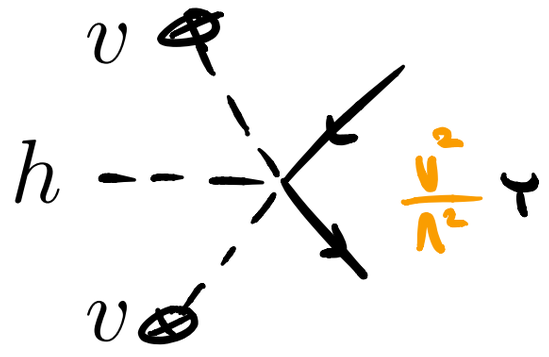

All tree-level **Higgs Couplings** are modified

Giudice,Grojean,Pomarol,Rattazzi'08;
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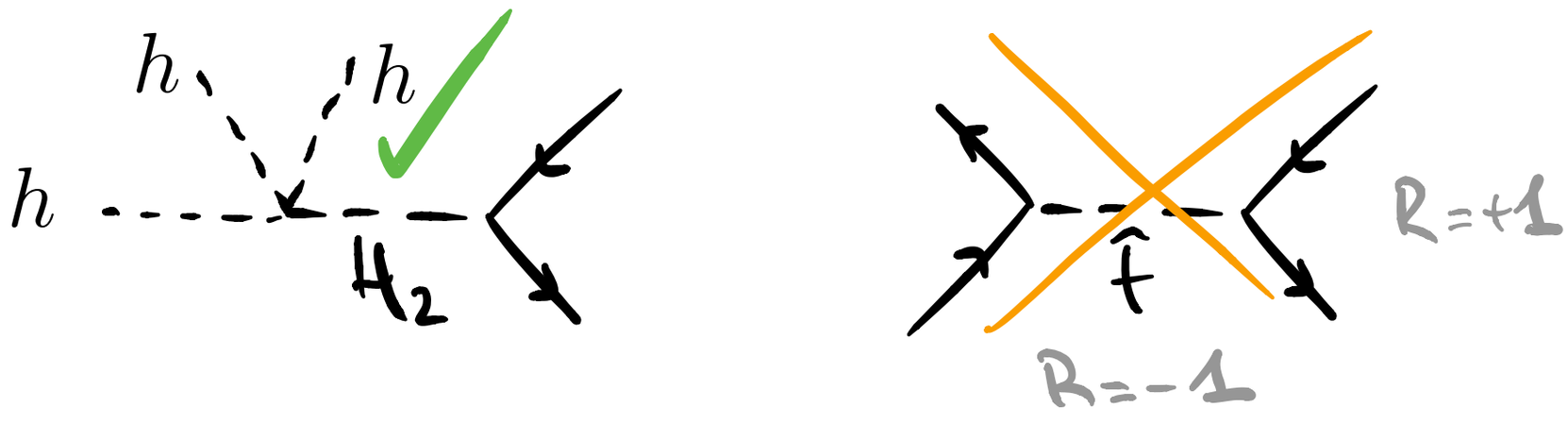
Supersymmetry: only H_2 (second Higgs) exchanged at tree-level (R-parity)



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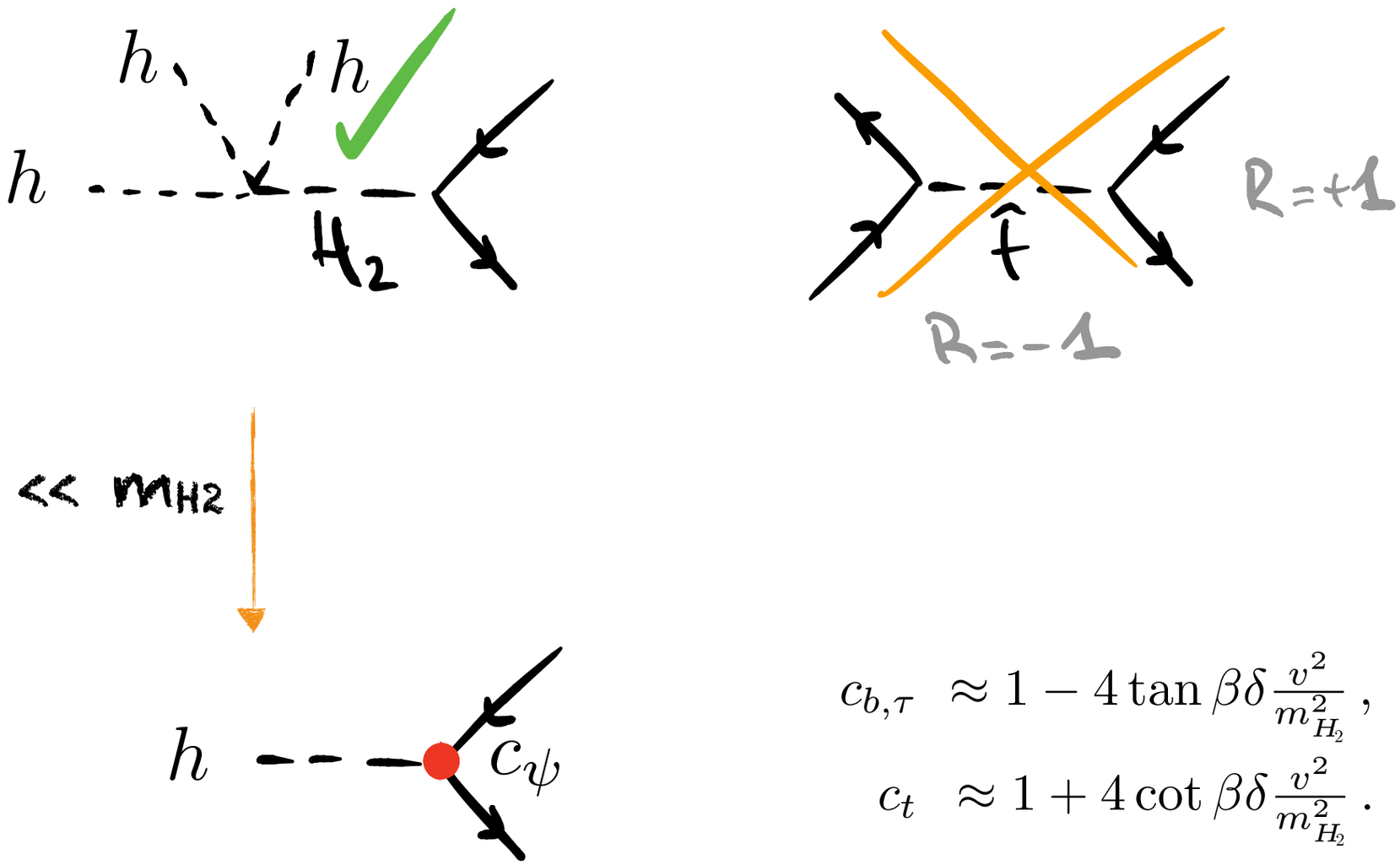

$$c_{b,\tau} \approx 1 - 4\tan\beta\delta\frac{v^2}{m_{H_2}^2}\,,$$
$$c_t \approx 1 + 4\cot\beta\delta\frac{v^2}{m_{H_2}^2}\,.$$

Gupta,Montull,FR'12

Higgs couplings to top/bottom are modified

BSM Perspective

What do we expect from a theory point of view?

▼

Higgs couplings

Are among the most important tests of new physics

(reasons: hierarchy problem, h-sector unexplored)

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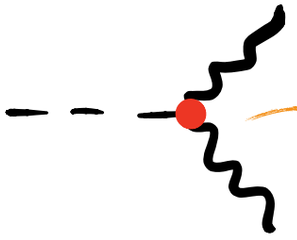

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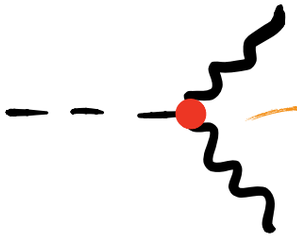

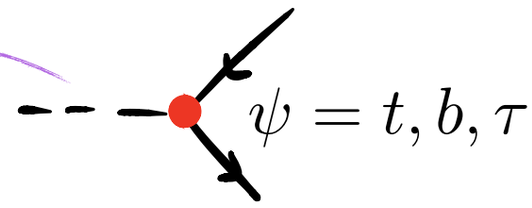

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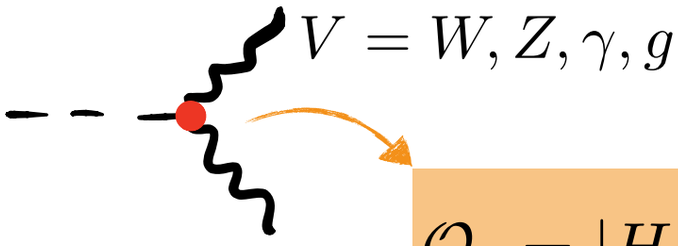

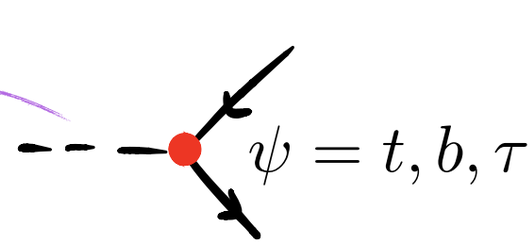

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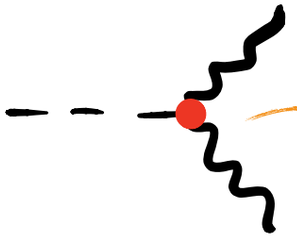

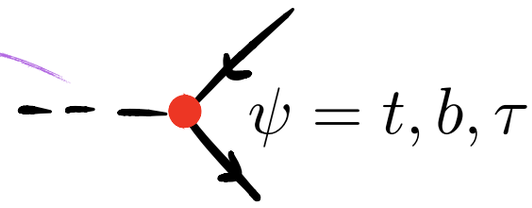

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...and more

Higgs Couplings at High-Energy

Higgs couplings: Theoretically Interesting

Experimentally not High-E measurements

ZH, WH or VBF at high-E? Higgs Couplings: no Energy-growth in Higgs processes

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but...

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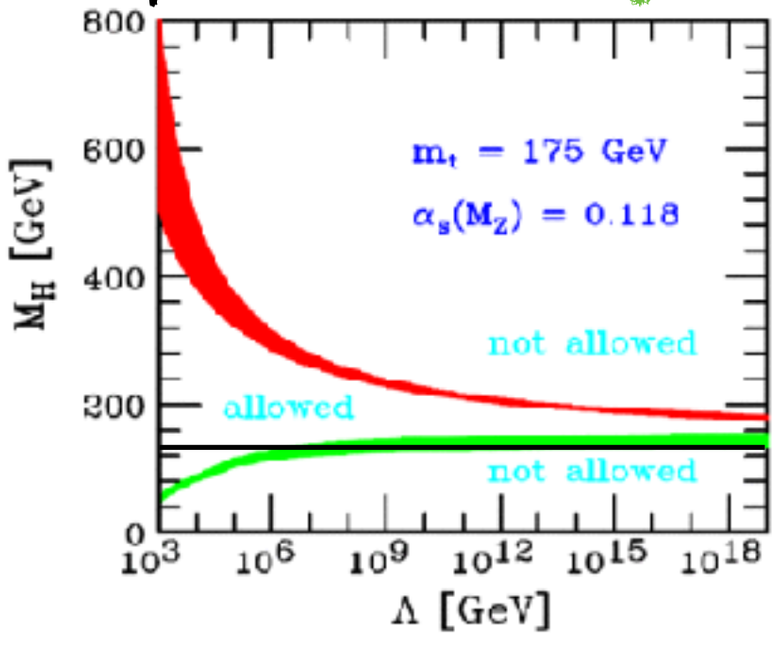
valid up to arbitrary energy:



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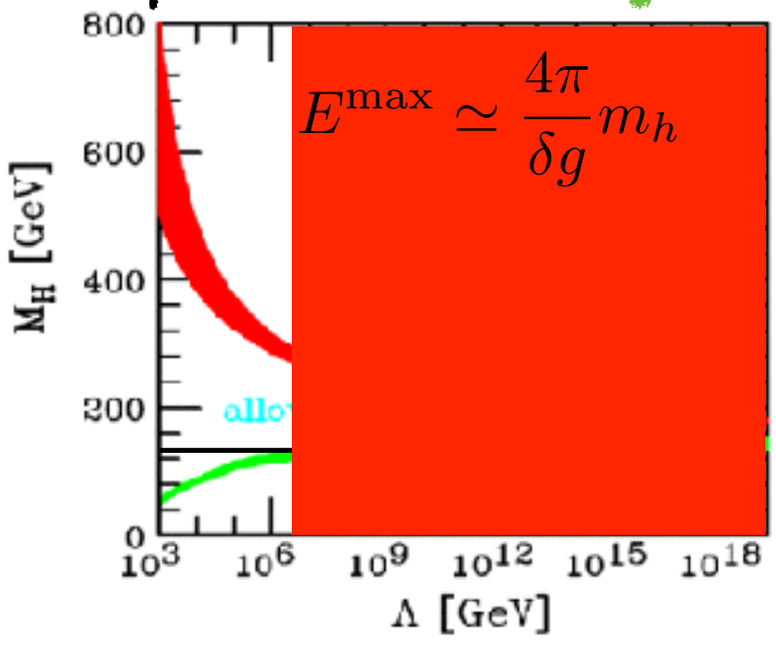

Any coupling modification must induce energy-growth in some process, reducing the validity energy-range

Higgs Couplings... without a Higgs

Henning,Lombardo,Riembau,FR'18

Any modifications of Higgs couplings induces

E^2 growth in some process with longitudinal W,Z bosons!

Higgs Couplings... without a Higgs

Henning,Lombardo,Riembau,FR'18

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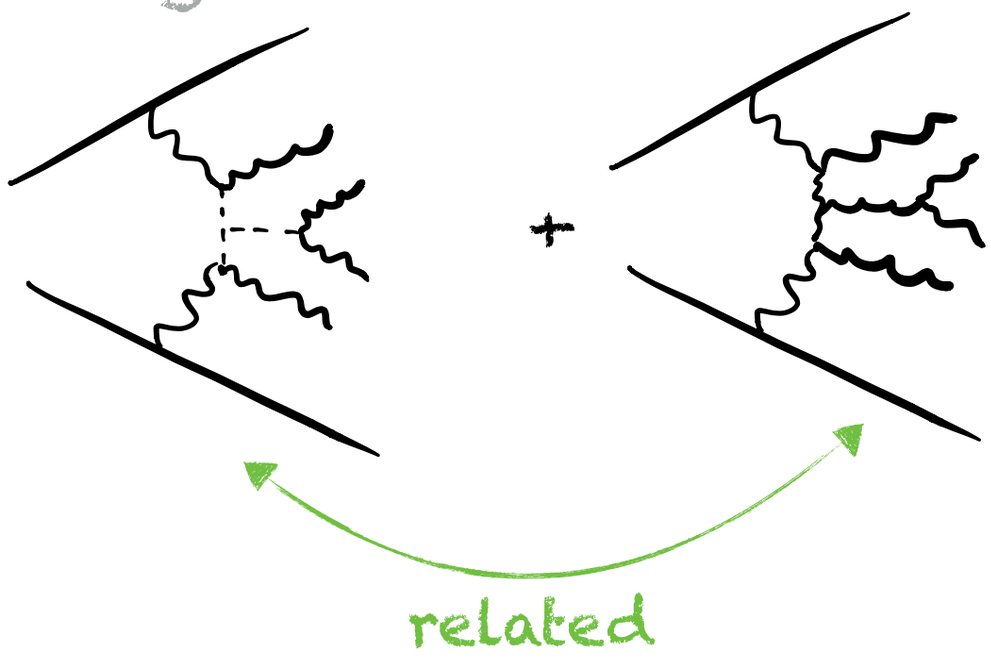
E^2 growth in some process with longitudinal W,Z bosons!

One way of seeing this:

SM = 

= finite

Higgs Couplings... without a Higgs

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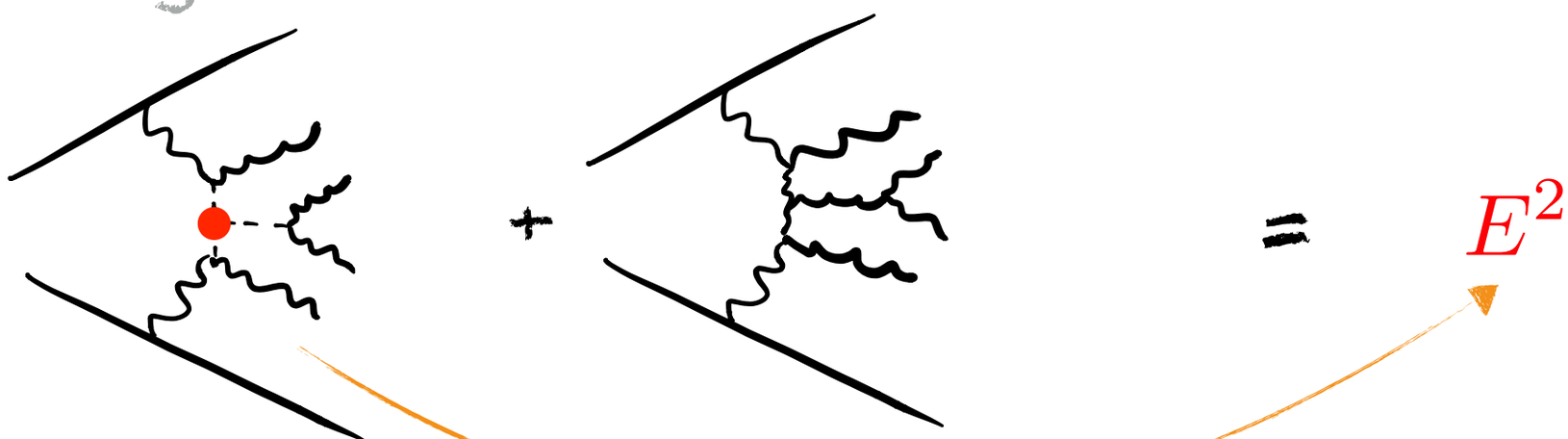
SM = 

modification of a coupling (h^3)
compromises gauge
cancellations in the SM

Higgs Self Coupling

Another way of understanding E-growth:

$$h^3 \in \frac{|H|^6}{\Lambda^2}$$

Golstones = W_L, Z_L

$$|H|^2 = \frac{1}{2}\left(v^2 + 2hv + h^2 + 2\phi^+\phi^- + (\phi^0)^2\right)$$

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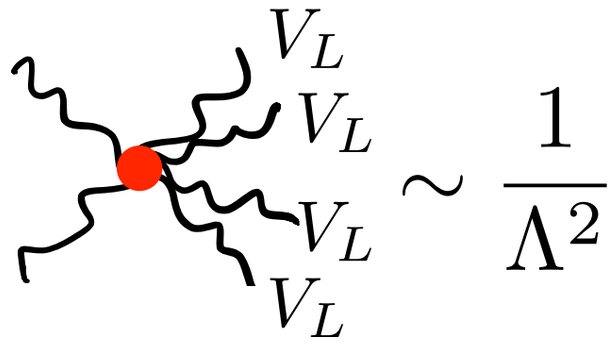

$$\sim \frac{1}{\Lambda^2}$$

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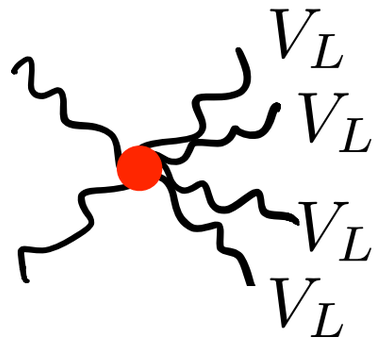

$\sim \frac{E^2}{\Lambda^2}$ w.r.t SM

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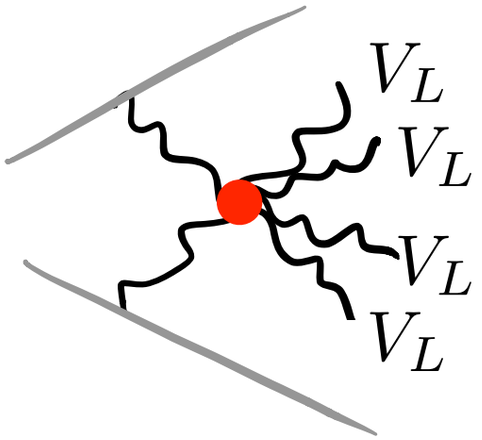

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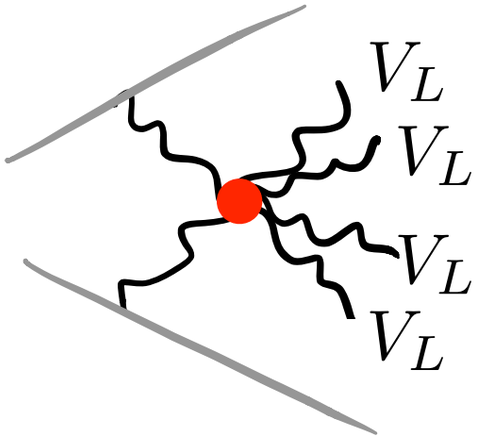

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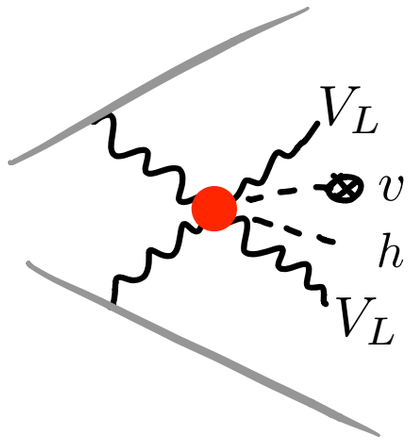

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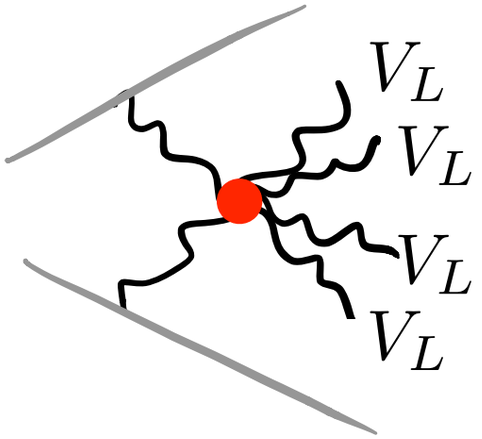

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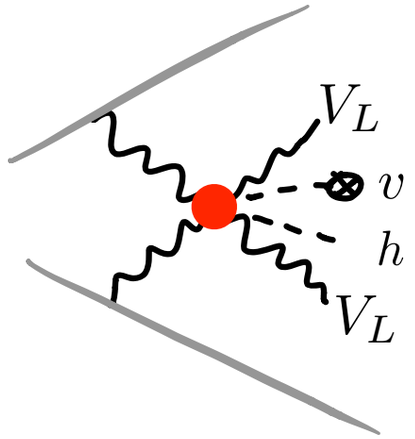

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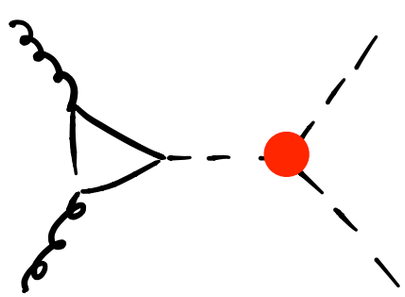
$pp \to jjh + V_L V_L'$

▶ with 3 Higgs v.e.v.s

(= traditional Higgs Coupling measurement)



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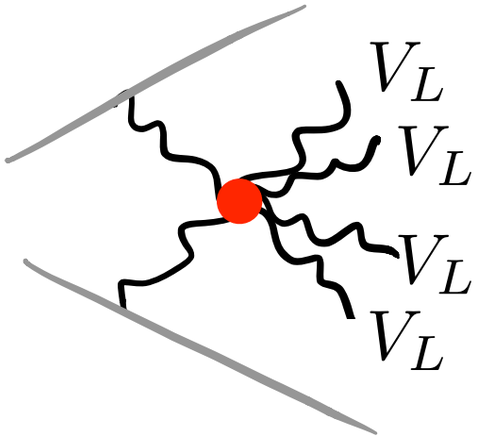

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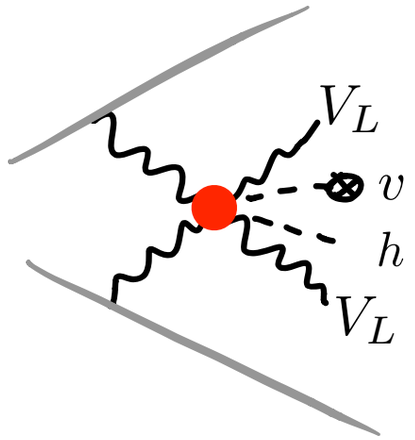

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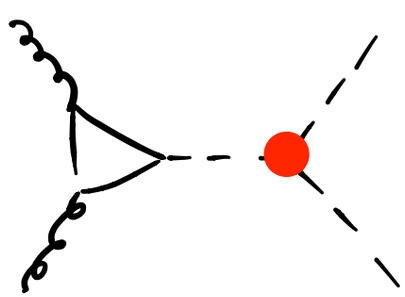

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signal

statistics

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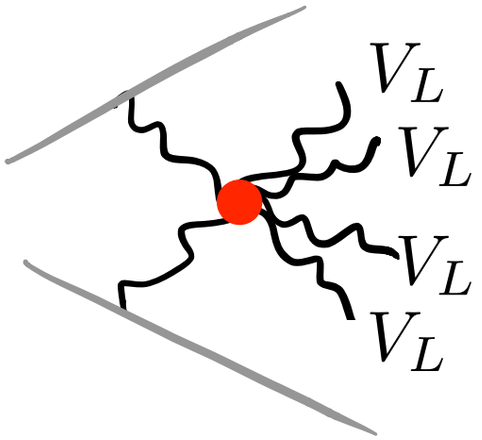

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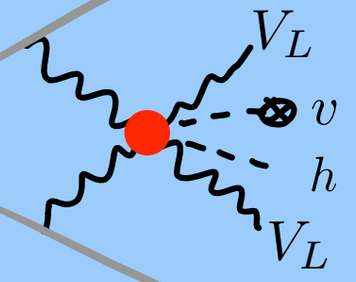

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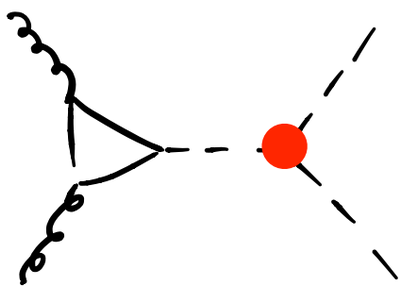

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Higgs Self Coupling - LHC

$$pp \to jjh + W^{\pm}W^{\pm}$$

Higgs Self Coupling - LHC

$W \to l + \nu$ → Same-sign leptons

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VBF topology

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VBF topology

- Enough events
  (50 events @ 3000 fb^{-1})
- Low background B
  - ttjj ✓
  - fake leptons ?

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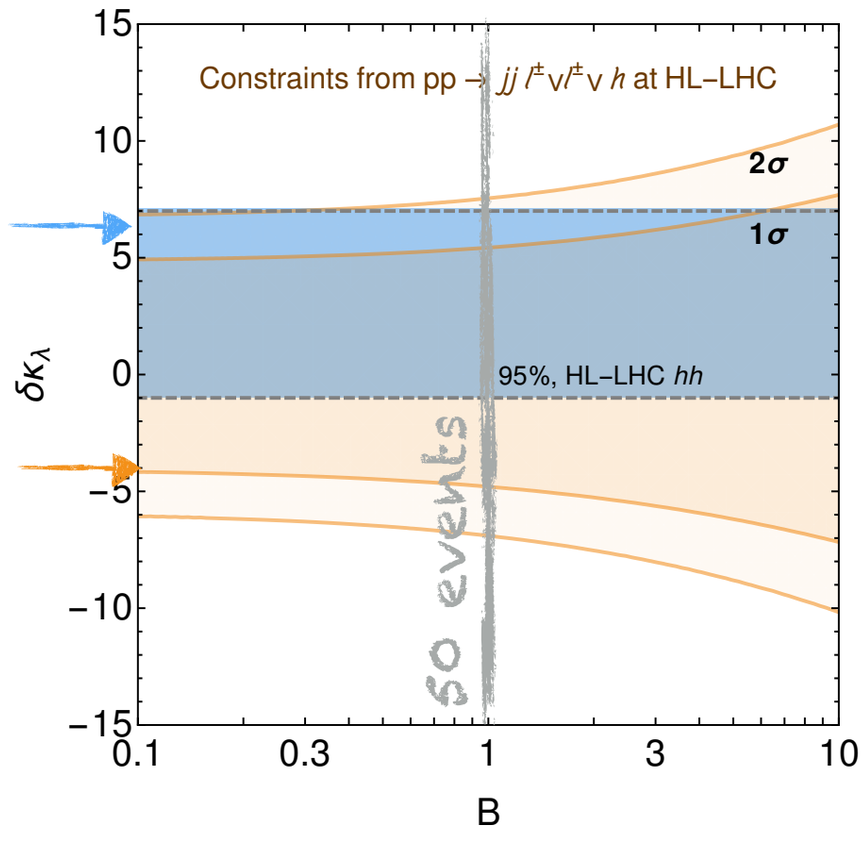
Standard Higgs Coupling Measurements (HC)

High-E Higgs without Higgs (HwH)



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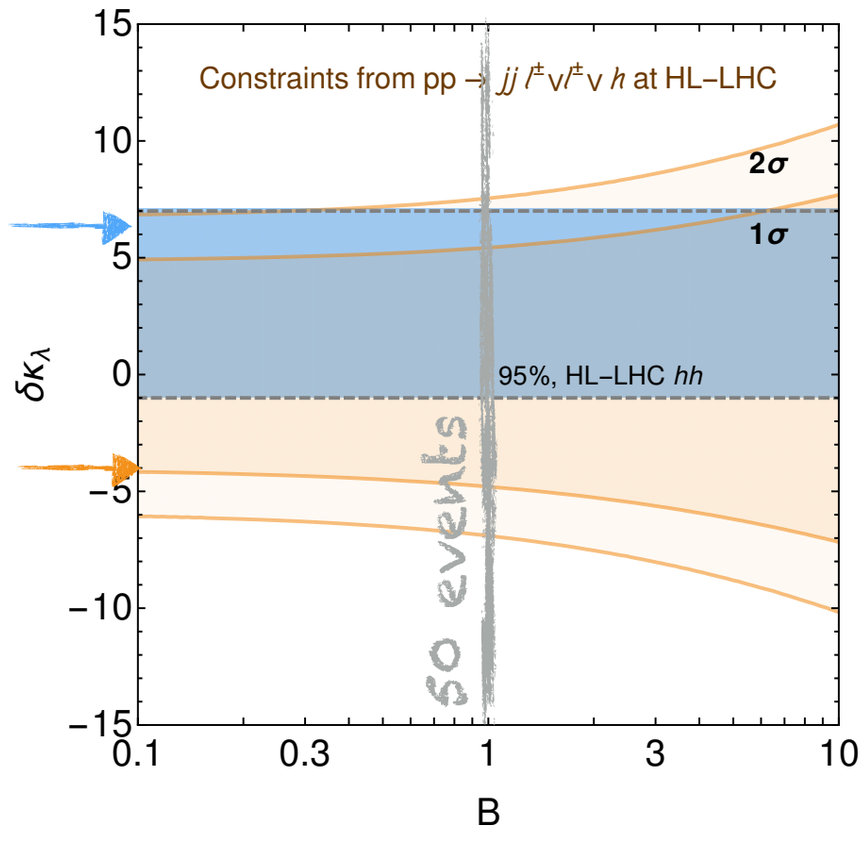


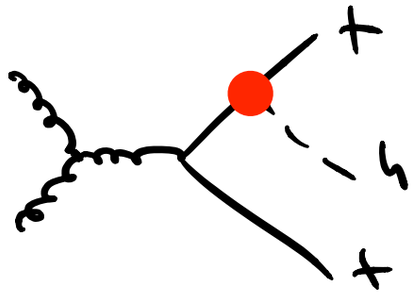
- HwH: single channel, simple analysis, competitive with HC!

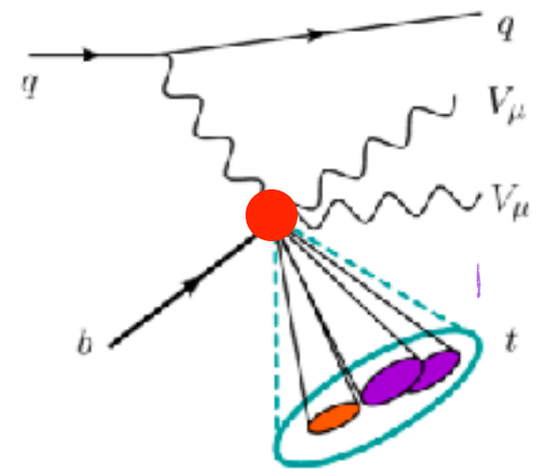
HwH Program - LHC

$\sim const$

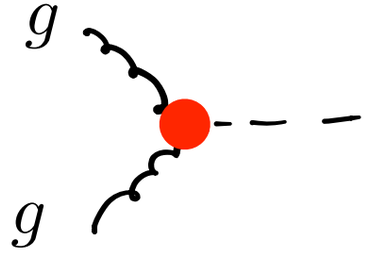
$\sim E^2$

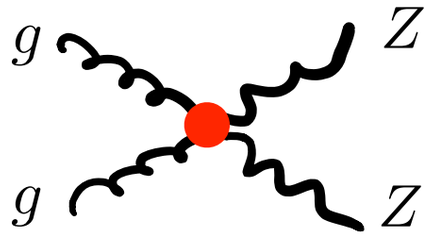
κ_t
$|H|^2 Q \tilde{H} t_R$



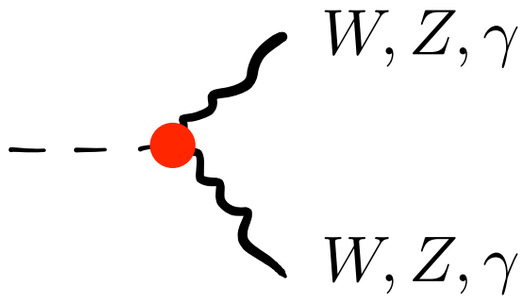


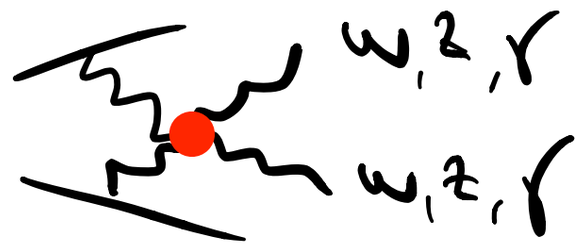
κ_G
$|H|^2 G^a_{\mu\nu} G^{a\,\mu\nu}$



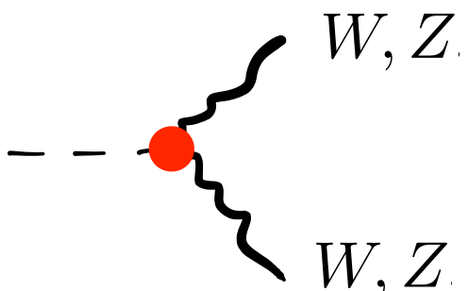


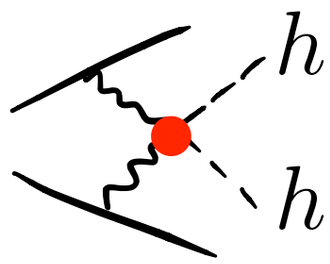
$\kappa_\gamma \quad |H|^2 B_{\mu\nu} B^{\mu\nu}$
$\kappa_{Z\gamma} \; |H|^2 W^a_{\mu\nu} W^{a\,\mu\nu}$





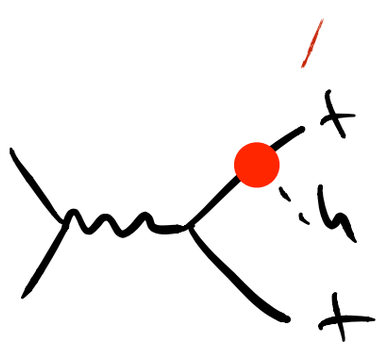
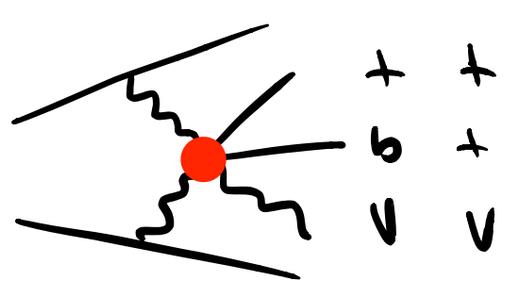
$\kappa_V \quad |H|^2 \partial_\mu H^\dagger \partial^\mu H$





HwH Program at Lepton Colliders
(different w.r.t LHC)

w.r.t. LEP: $\left(\frac{3000}{91.2}\right)^2 \approx 1000$ times larger

	HC	HwH $\sim E^2$
κ_t		

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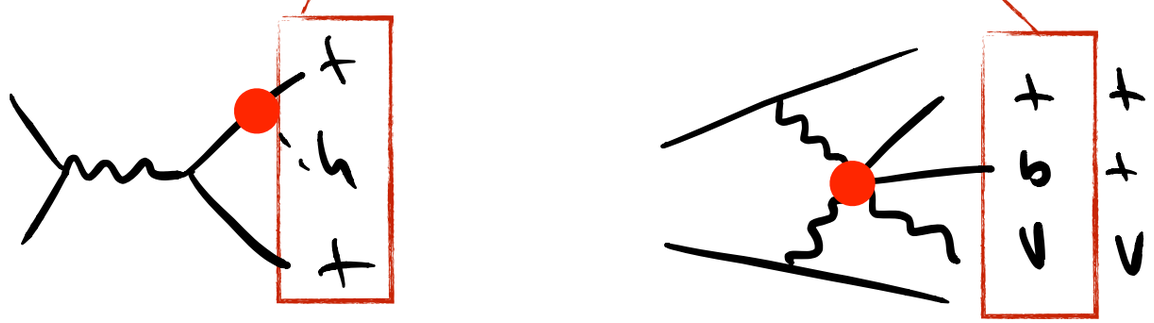
HC

HwH $\sim E^2$

lower threshold

κ_t



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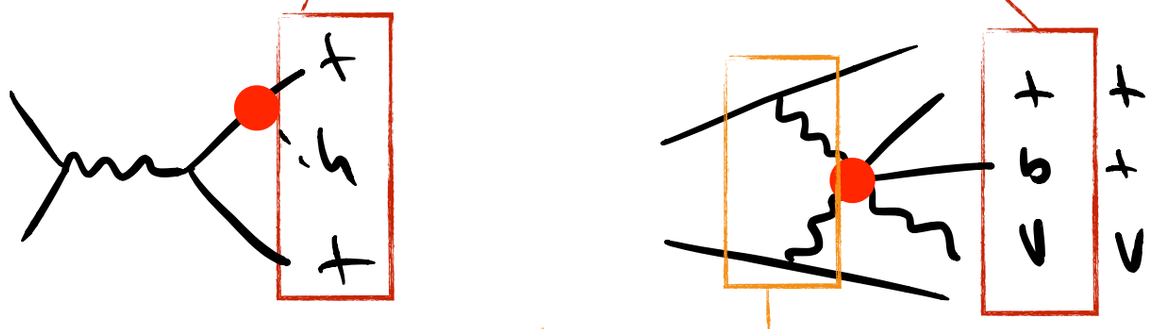
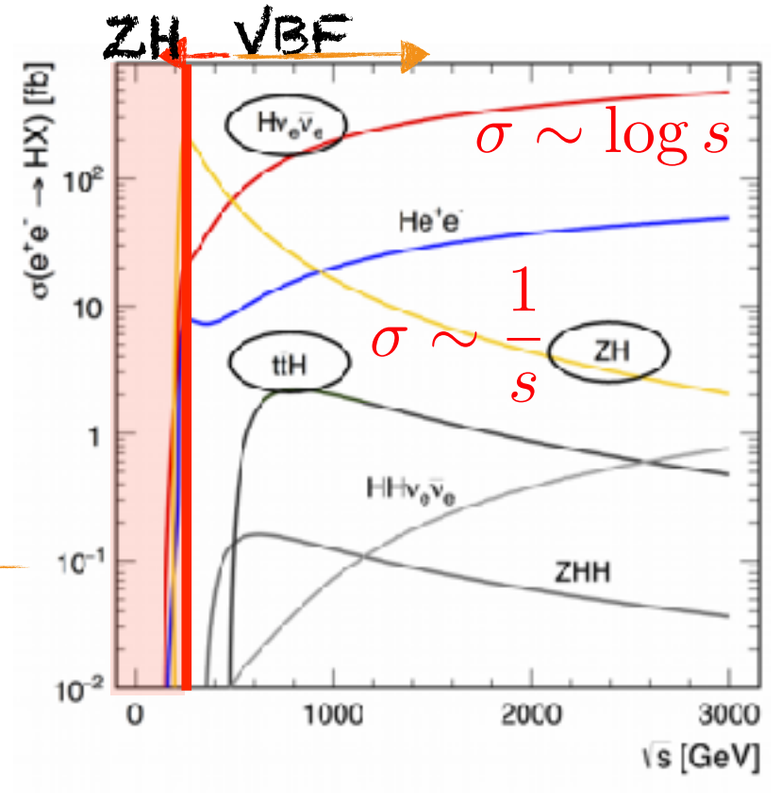


VBF xsec larger



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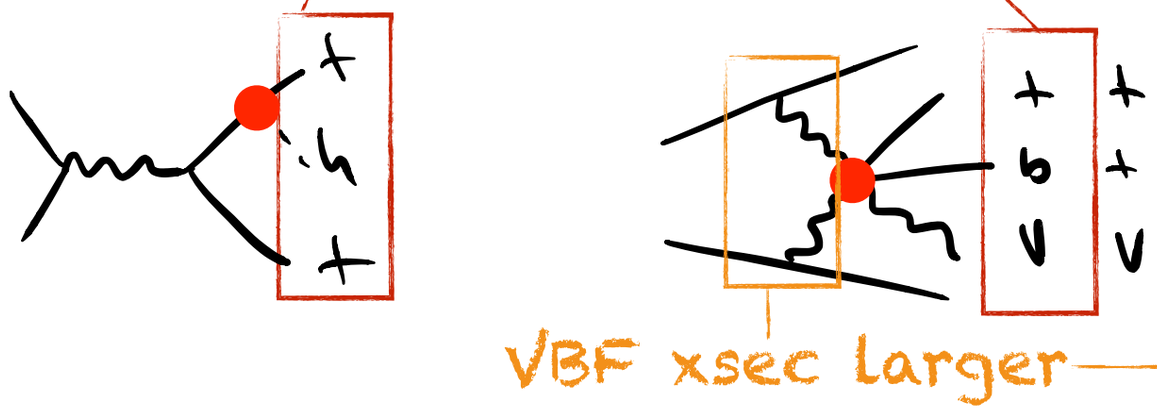

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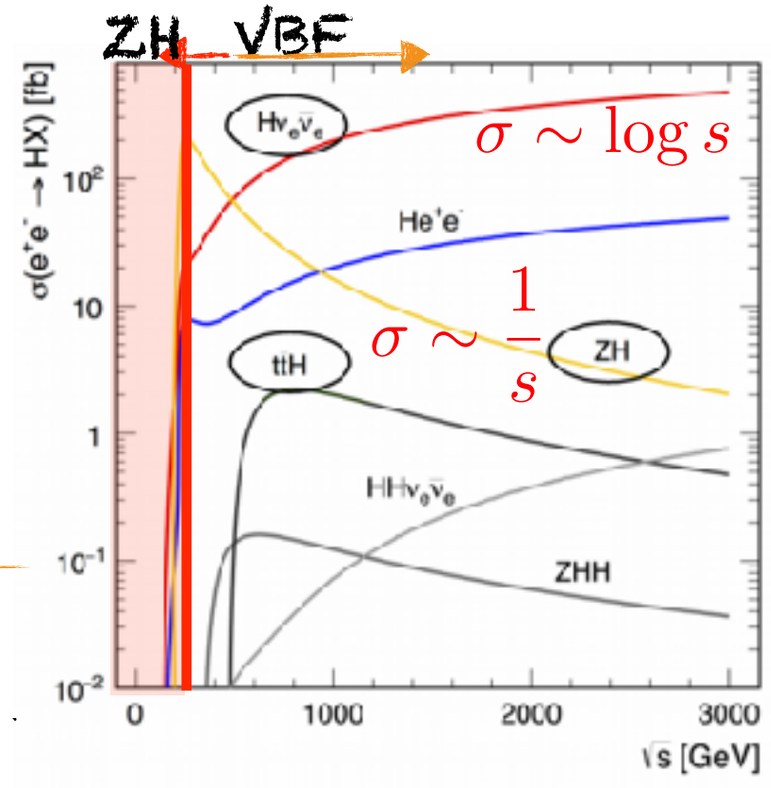

Poorly measured at ee-colliders

κ_G

Beam Polarization:
Enhance LL?

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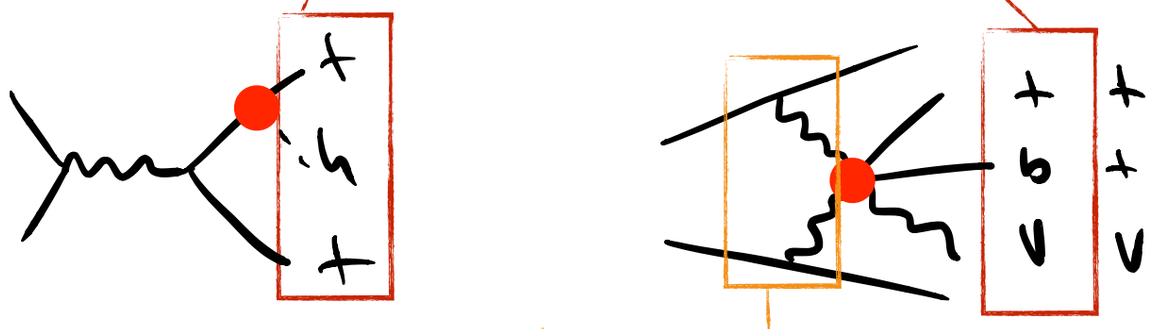

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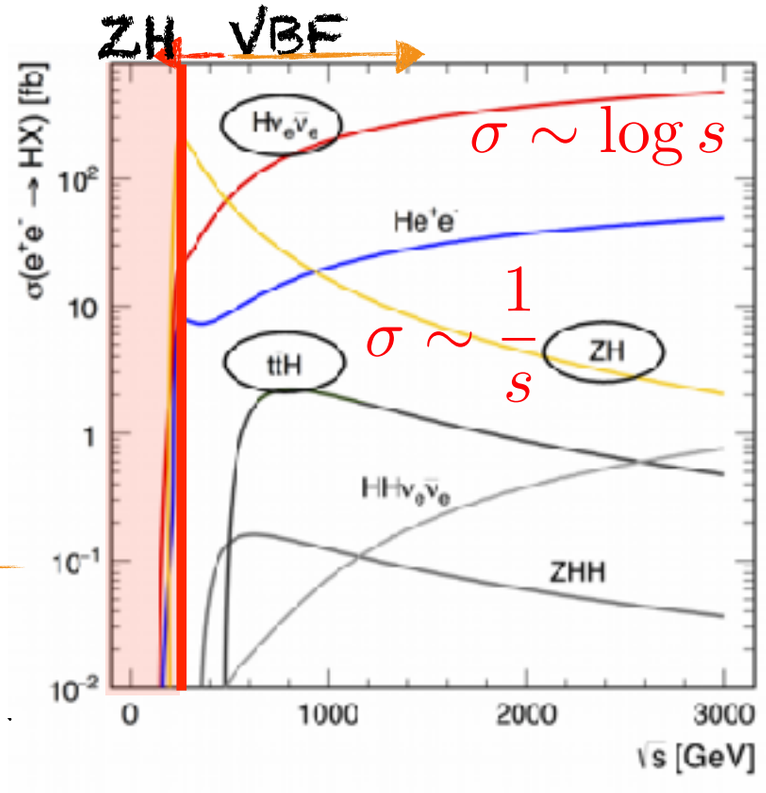

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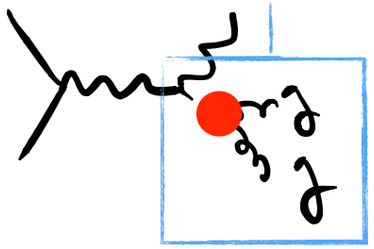
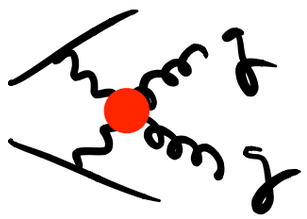
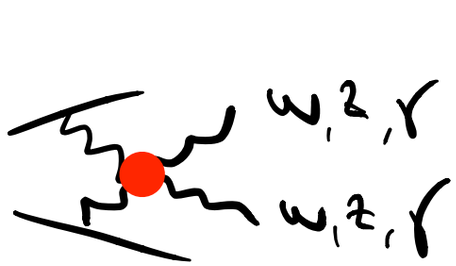
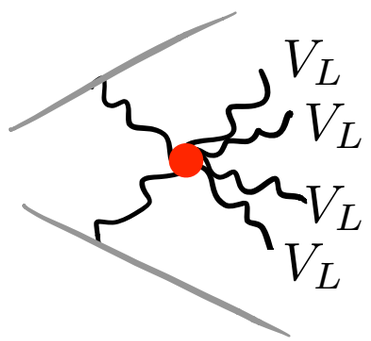


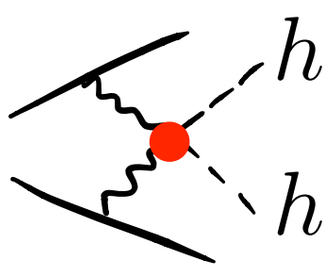


Beam Polarization: Enhance LL?

κ_γ
$\kappa_{Z\gamma}$
κ_V
κ_λ



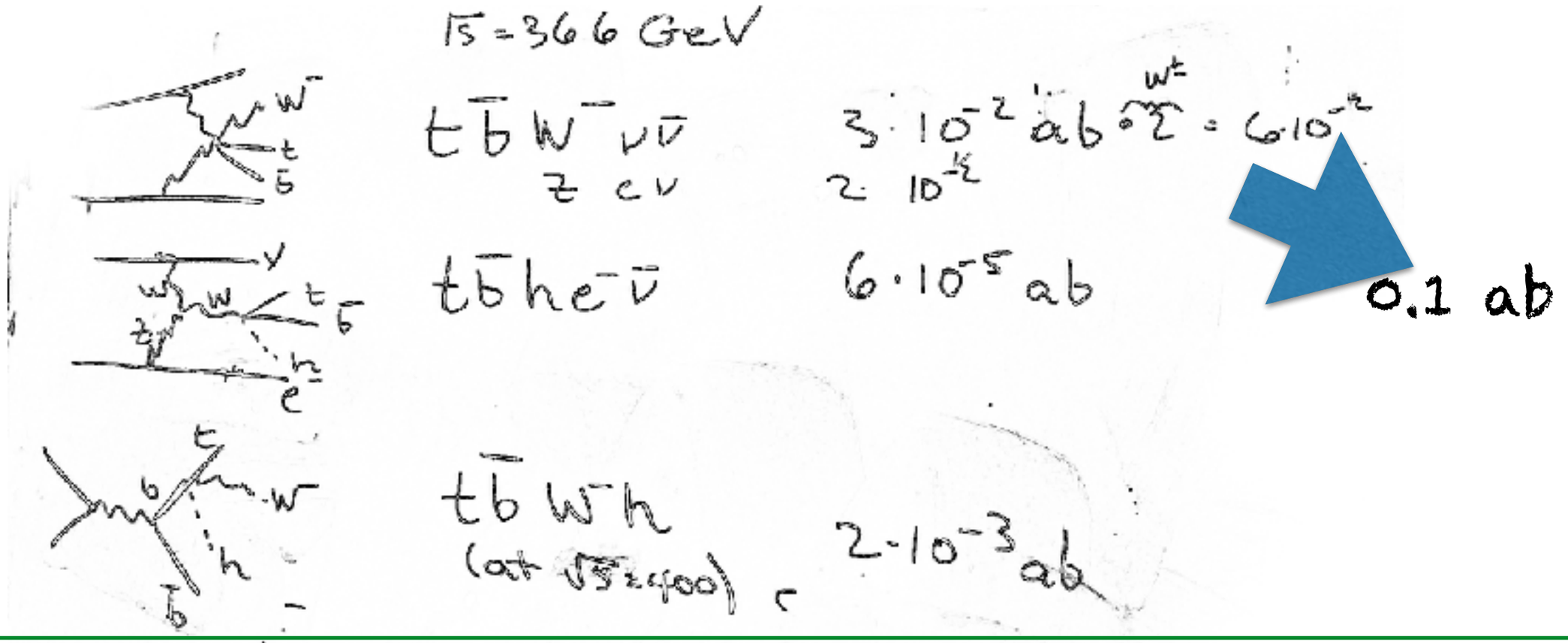




Similar to LHC

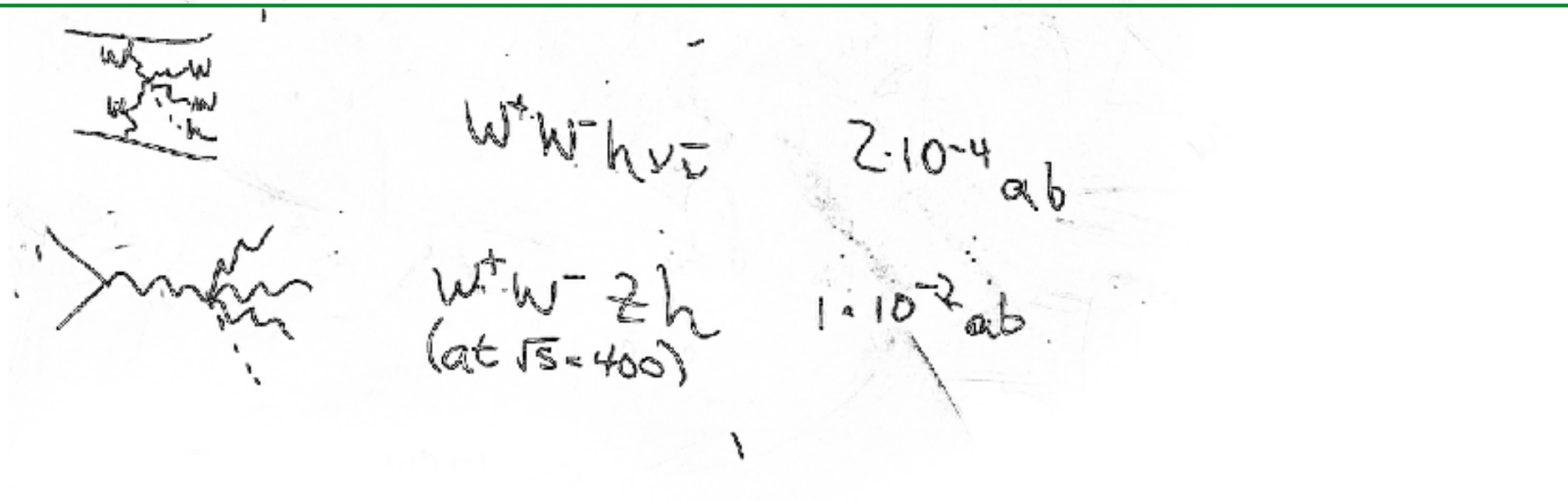
FCCee estimates

κ_t
$|H|^2 Q \tilde{H} t_R$



0.1 ab

κ_λ
$\mathcal{O}_6 = |H|^6$



FCCee estimates

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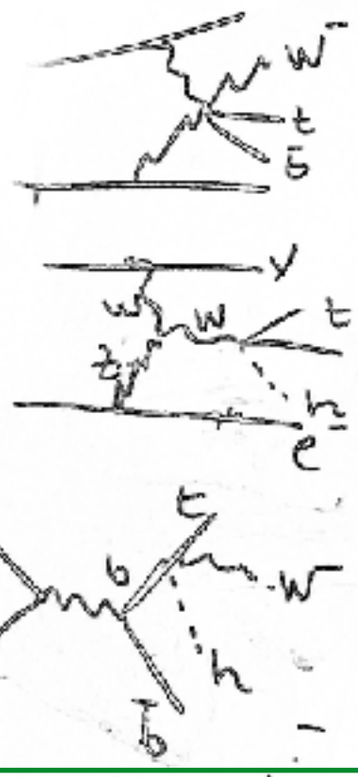
$|H|^2 Q \tilde{H} t_R$

$\sqrt{s} = 366$ GeV



$t\bar{t}W^-\nu\bar{\nu}$ $\quad 3\cdot 10^{-2}$ ab $\quad \sigma^{W^\pm} = 6\cdot 10^{-2}$

$t\bar{t}Ze\nu$ $\quad 2\cdot 10^{-4}$

$t\bar{t}he^-\bar{\nu}$ $\quad 6\cdot 10^{-5}$ ab

0.1 ab

(at $\sqrt{s} = 450$: $\sigma_{ab} \times 3 \sim 2\cdot 10^{-3}$ ab)

$t\bar{t}W^-h$ (at $\sqrt{s} = 400$) $\quad 2\cdot 10^{-3}$ ab

κ_λ
$\mathcal{O}_6 = |H|^6$

$W^+W^-h\nu\bar{\nu}$ $\quad 2\cdot 10^{-4}$ ab

W^+W^-Zh (at $\sqrt{s} = 400$) $\quad 1\cdot 10^{-2}$ ab