



Genova Boccadasse

High p_T observables impact on global fit

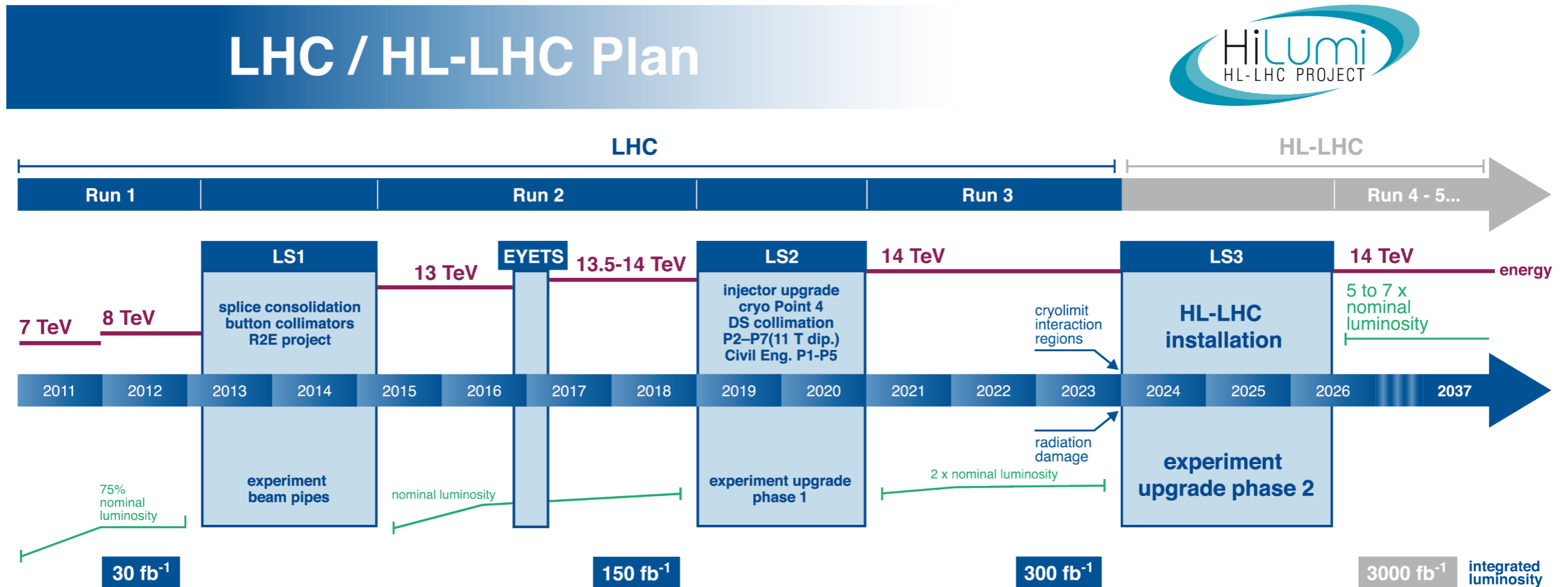
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LHC physics program



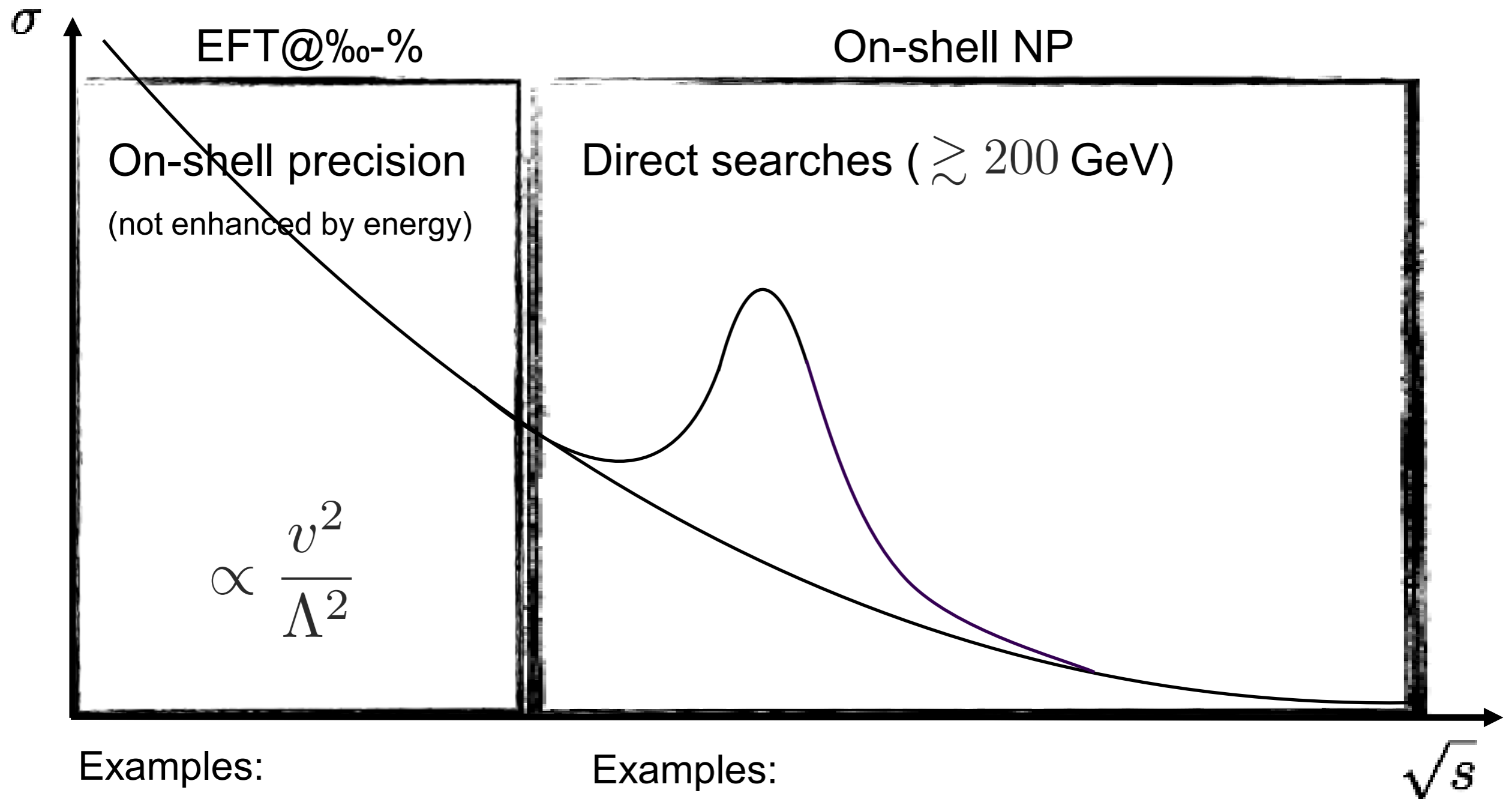
Main goal: Find signs of New Physics

- directly: probing on-shell new physics
- indirectly: probing the effect of new physics on SM observables

direct searches

precision physics

New Physics sketch: beginning of LHC



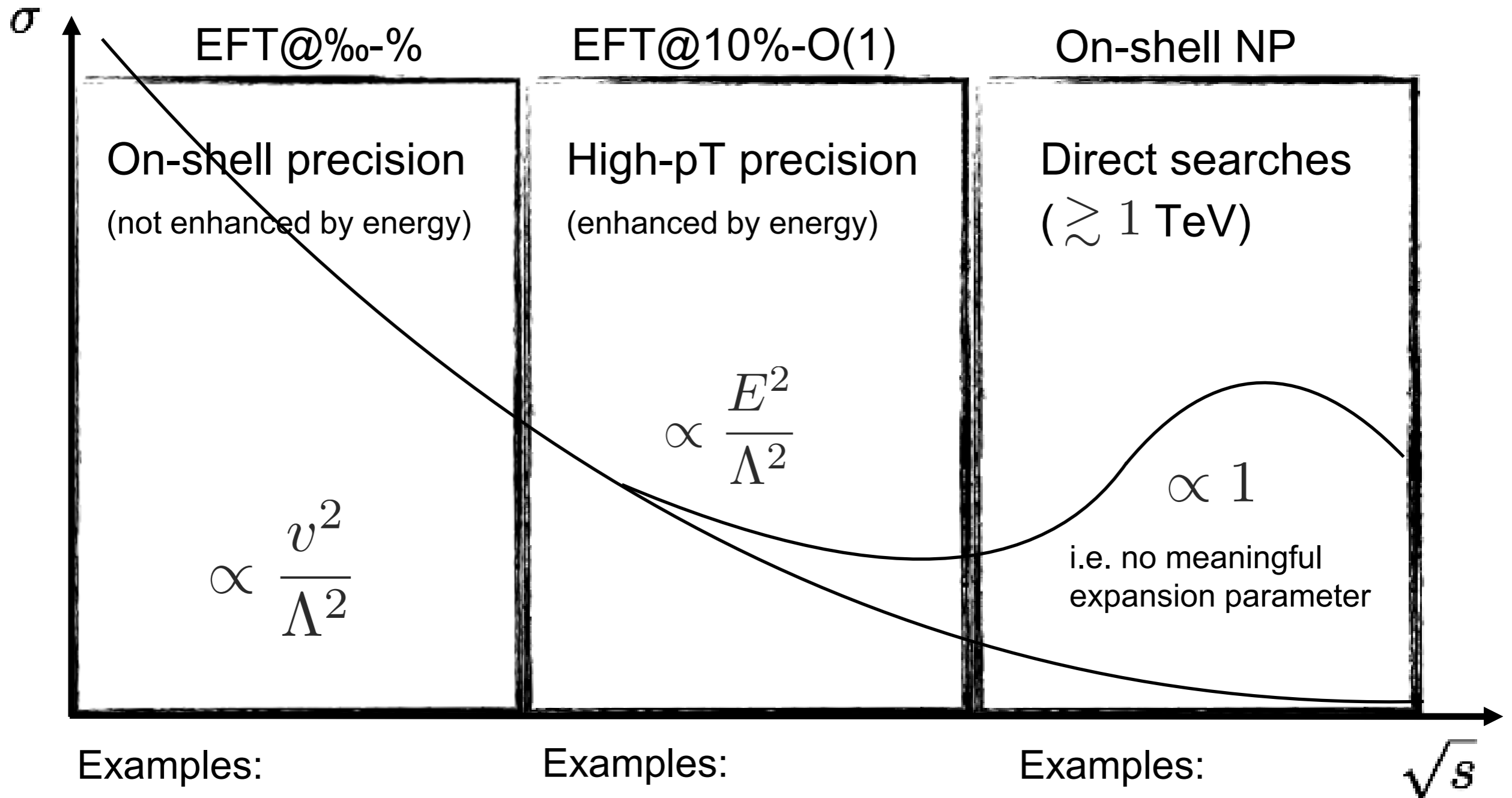
Examples:

- SM parameters
- Pole observables
e.g. \hat{S} , \hat{T} , etc.
- Higgs observables*

Examples:

- SUSY
- Top partners
- Resonances

New Physics sketch: now



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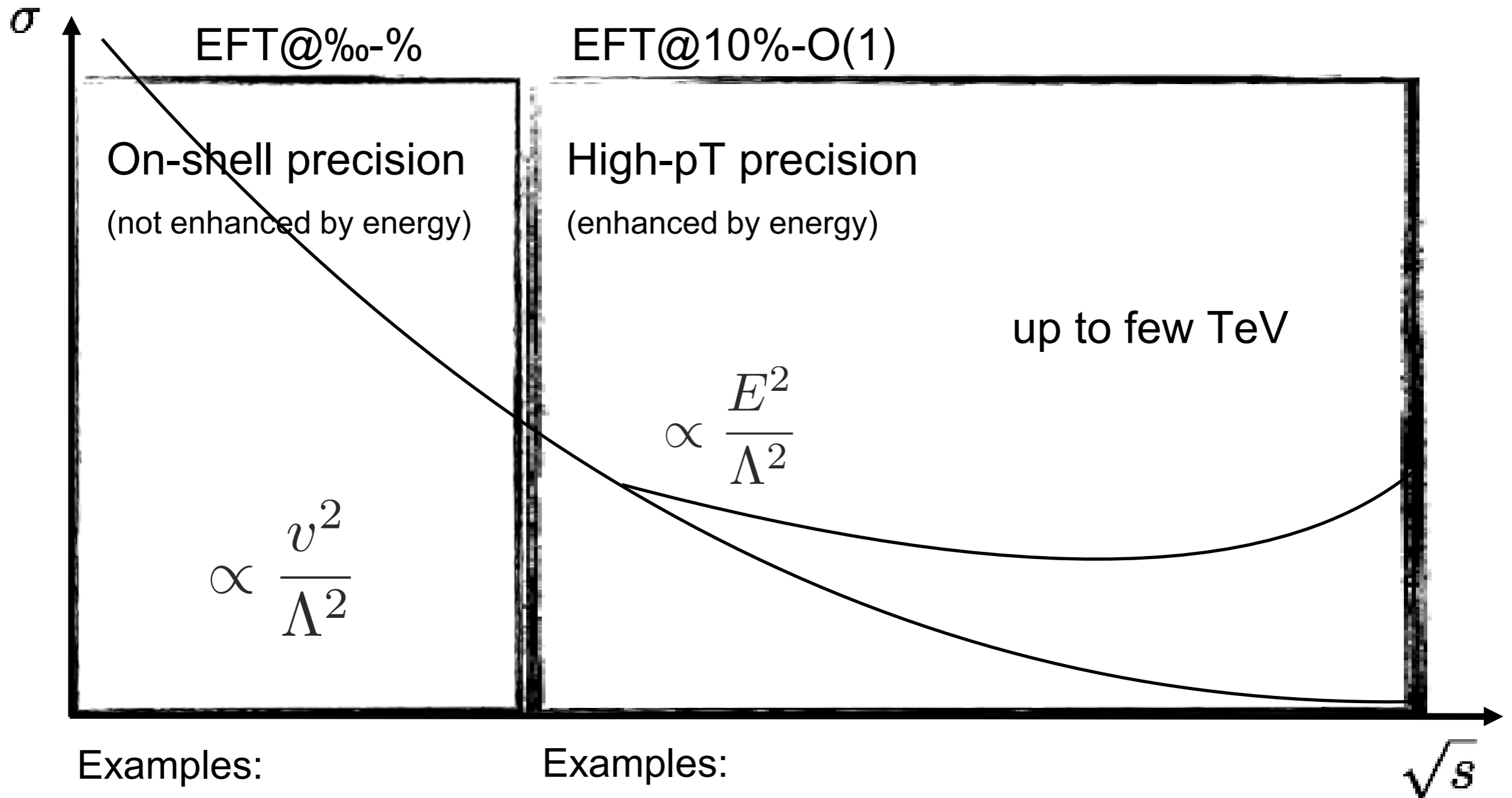
Examples:

- DY (e.g. W , Y , etc.)
- Di-bosons
- Di-jets
- Heavy quarks ($t\bar{t}$, ...)

Examples:

- SUSY
- Top partners
- Resonances

New Physics : end of LHC



Examples:

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e.g. \hat{S} , \hat{T} , etc.
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Direct searches

ATLAS SUSY Searches* - 95% CL Lower Limits

July 2020

Model	Signature	$\int L dt$ [fb ⁻¹]	Mass limit	Reference				
Inclusive Searches	$q\bar{q}, \bar{q} \rightarrow q\bar{q} \ell^0$	0 e, μ	2-6 jets	E_T^{miss}	139	\bar{q} [10x Degen] 1.9 \bar{q} [1x, 8x Degen] 0.43, 0.71 Forbidden 1.15-1.95 2.35 2.2 1.2 1.97 1.15 2.25 1.25	$m(\tilde{t}_1) < 400$ GeV $m(\tilde{q}) - m(\tilde{t}_1) = 5$ GeV $m(\tilde{t}_1) < 500$ GeV $m(\tilde{q}) - m(\tilde{t}_1) = 50$ GeV $m(\tilde{t}_1) < 500$ GeV $m(\tilde{q}) - m(\tilde{t}_1) = 200$ GeV $m(\tilde{t}_1) < 200$ GeV $m(\tilde{q}) - m(\tilde{t}_1) = 300$ GeV	ATLAS-CONF-2019-040 1711.03301 ATLAS-CONF-2019-040 ATLAS-CONF-2019-040 ATLAS-CONF-2020-047 1805.11381 ATLAS-CONF-2020-002 1909.08457 ATLAS-CONF-2018-041 1909.08457
	$\bar{q}\bar{q}, \bar{q} \rightarrow q\bar{q} \ell^0$	0 e, μ	2-6 jets	E_T^{miss}	139		$m(\tilde{t}_1) < 400$ GeV $m(\tilde{q}) - m(\tilde{t}_1) = 5$ GeV	ATLAS-CONF-2019-040 ATLAS-CONF-2019-040
	$\bar{q}\bar{q}, \bar{q} \rightarrow q\bar{q} W \ell^0$	1 e, μ	2-6 jets	E_T^{miss}	139		$m(\tilde{t}_1) < 500$ GeV	ATLAS-CONF-2020-047
	$\bar{q}\bar{q}, \bar{q} \rightarrow q\bar{q} \ell \ell^0$	ee, $\mu\mu$	2 jets	E_T^{miss}	139		$m(\tilde{t}_1) < 500$ GeV	1805.11381
	$\bar{q}\bar{q}, \bar{q} \rightarrow q\bar{q} W Z \ell^0$	0 e, μ	7-11 jets	E_T^{miss}	139		$m(\tilde{t}_1) < 500$ GeV	ATLAS-CONF-2020-002
	$\bar{q}\bar{q}, \bar{q} \rightarrow q\bar{q} W Z \ell^0$	SS e, μ	6 jets	E_T^{miss}	139		$m(\tilde{t}_1) < 200$ GeV	1909.08457
3rd gen. squarks direct production	$\bar{b}\bar{b}, \bar{b} \rightarrow b\bar{b} \ell^0$	0 e, μ	Multiple	E_T^{miss}	36.1	Forbidden 0.74, 0.9 Forbidden 0.13-0.85, 0.23-1.35 1.25 0.44-0.59 1.16 0.46, 0.85 0.43 0.067-1.18 0.86 0.205, 0.64 0.42, 0.74 1.0 0.7 0.256 0.13-0.23, 0.29-0.88 0.15, 0.46 2.0	$m(\tilde{t}_1) < 200$ GeV, $m(\tilde{b}_1) - m(\tilde{t}_1) = 1$ $\Delta m(\tilde{t}_1, \tilde{b}_1) = 130$ GeV, $m(\tilde{t}_1) = 100$ GeV $\Delta m(\tilde{t}_1, \tilde{b}_1) = 130$ GeV, $m(\tilde{t}_1) = 0$ GeV $m(\tilde{t}_1) = 1$ GeV $m(\tilde{t}_1) = 400$ GeV $m(\tilde{t}_1) = 800$ GeV $m(\tilde{t}_1) = 0$ GeV $m(\tilde{t}_1) = 50$ GeV $m(\tilde{t}_1) = 50$ GeV $m(\tilde{t}_1) = 500$ GeV $m(\tilde{t}_1) = 360$ GeV, $m(\tilde{b}_1) - m(\tilde{t}_1) = 40$ GeV	1708.09286, 1711.03301 1909.08457 1908.08122 ATLAS-CONF-2020-031 ATLAS-CONF-2020-003, 2004.14060 ATLAS-CONF-2019-017 1803.10178 1805.01649 1805.01649 1711.03301 SUSY-2018-09 SUSY-2018-09
	$\bar{b}\bar{b}, \bar{b} \rightarrow b\bar{b} \ell^0$	0 e, μ	6 b	E_T^{miss}	139		$m(\tilde{t}_1) < 400$ GeV	1708.09286, 1711.03301
	$\bar{b}\bar{b}, \bar{b} \rightarrow b\bar{b} \ell^0$	0 e, μ	2 b	E_T^{miss}	139		$m(\tilde{t}_1) < 400$ GeV	1708.09286, 1711.03301
	$\bar{b}\bar{b}, \bar{b} \rightarrow b\bar{b} \ell^0$	0-1 e, μ	≥ 1 jet	E_T^{miss}	139		$m(\tilde{t}_1) < 400$ GeV	ATLAS-CONF-2020-003, 2004.14060
	$\bar{b}\bar{b}, \bar{b} \rightarrow b\bar{b} \ell^0$	1 e, μ	3 jets/1 b	E_T^{miss}	139		$m(\tilde{t}_1) < 400$ GeV	ATLAS-CONF-2019-017
	$\bar{b}\bar{b}, \bar{b} \rightarrow b\bar{b} \ell^0$	1 τ + 1 e, μ , τ	2 jets/1 b	E_T^{miss}	36.1		$m(\tilde{t}_1) < 400$ GeV	1803.10178
EW direct	$\bar{t}\bar{t}, \bar{t} \rightarrow t\bar{t} \ell^0$	0 e, μ	Multiple	E_T^{miss}	36.1	0.46, 0.85 0.43 0.067-1.18 0.86 0.205, 0.64 0.42, 0.74 1.0 0.7 0.256 0.13-0.23, 0.29-0.88 0.15, 0.46 2.0	$m(\tilde{t}_1) < 400$ GeV $m(\tilde{t}_1) = 0$ GeV $m(\tilde{t}_1) = 50$ GeV $m(\tilde{t}_1) = 100$ GeV $m(\tilde{t}_1) = 500$ GeV $m(\tilde{t}_1) = 360$ GeV, $m(\tilde{b}_1) - m(\tilde{t}_1) = 40$ GeV	1708.09286, 1711.03301 1909.08457 1908.08122 ATLAS-CONF-2020-031 ATLAS-CONF-2020-003, 2004.14060 ATLAS-CONF-2019-017 1803.10178 1805.01649 1805.01649 1711.03301 SUSY-2018-09 SUSY-2018-09
	$\bar{t}\bar{t}, \bar{t} \rightarrow t\bar{t} \ell^0$	0 e, μ	Multiple	E_T^{miss}	36.1		$m(\tilde{t}_1) < 400$ GeV	1708.09286, 1711.03301
	$\bar{t}\bar{t}, \bar{t} \rightarrow t\bar{t} \ell^0$	0 e, μ	2 b	E_T^{miss}	139		$m(\tilde{t}_1) < 400$ GeV	1708.09286, 1711.03301
	$\bar{t}\bar{t}, \bar{t} \rightarrow t\bar{t} \ell^0$	0-1 e, μ	≥ 1 jet	E_T^{miss}	139		$m(\tilde{t}_1) < 400$ GeV	ATLAS-CONF-2020-003, 2004.14060
	$\bar{t}\bar{t}, \bar{t} \rightarrow t\bar{t} \ell^0$	1 e, μ	3 jets/1 b	E_T^{miss}	139		$m(\tilde{t}_1) < 400$ GeV	ATLAS-CONF-2019-017
	$\bar{t}\bar{t}, \bar{t} \rightarrow t\bar{t} \ell^0$	1 τ + 1 e, μ , τ	2 jets/1 b	E_T^{miss}	36.1		$m(\tilde{t}_1) < 400$ GeV	1803.10178
Long-lived particles	$\bar{t}\bar{t}, \bar{t} \rightarrow t\bar{t} \ell^0$	0 e, μ	Multiple	E_T^{miss}	36.1	0.46, 0.85 0.43 0.067-1.18 0.86 0.205, 0.64 0.42, 0.74 1.0 0.7 0.256 0.13-0.23, 0.29-0.88 0.15, 0.46 2.0	$m(\tilde{t}_1) < 400$ GeV $m(\tilde{t}_1) = 0$ GeV $m(\tilde{t}_1) = 50$ GeV $m(\tilde{t}_1) = 100$ GeV $m(\tilde{t}_1) = 500$ GeV $m(\tilde{t}_1) = 360$ GeV, $m(\tilde{b}_1) - m(\tilde{t}_1) = 40$ GeV	1708.09286, 1711.03301 1909.08457 1908.08122 ATLAS-CONF-2020-031 ATLAS-CONF-2020-003, 2004.14060 ATLAS-CONF-2019-017 1803.10178 1805.01649 1805.01649 1711.03301 SUSY-2018-09 SUSY-2018-09
	$\bar{t}\bar{t}, \bar{t} \rightarrow t\bar{t} \ell^0$	0 e, μ	Multiple	E_T^{miss}	36.1		$m(\tilde{t}_1) < 400$ GeV	1708.09286, 1711.03301
	$\bar{t}\bar{t}, \bar{t} \rightarrow t\bar{t} \ell^0$	0 e, μ	Multiple	E_T^{miss}	36.1		$m(\tilde{t}_1) < 400$ GeV	1708.09286, 1711.03301
	$\bar{t}\bar{t}, \bar{t} \rightarrow t\bar{t} \ell^0$	0-1 e, μ	2 b/2 γ	E_T^{miss}	139		$m(\tilde{t}_1) < 400$ GeV	ATLAS-CONF-2020-015 1911.12606
	$\bar{t}\bar{t}, \bar{t} \rightarrow t\bar{t} \ell^0$	2 e, μ	0 jets	E_T^{miss}	139		$m(\tilde{t}_1) < 400$ GeV	1908.08215
	$\bar{t}\bar{t}, \bar{t} \rightarrow t\bar{t} \ell^0$	0-1 e, μ	2 b/2 γ	E_T^{miss}	139		$m(\tilde{t}_1) < 400$ GeV	2004.10894, 1909.09226
RPV	$\bar{t}\bar{t}, \bar{t} \rightarrow t\bar{t} \ell^0$	0 e, μ	Multiple	E_T^{miss}	36.1	0.46, 0.85 0.43 0.067-1.18 0.86 0.205, 0.64 0.42, 0.74 1.0 0.7 0.256 0.13-0.23, 0.29-0.88 0.15, 0.46 2.0	$m(\tilde{t}_1) < 400$ GeV $m(\tilde{t}_1) = 0$ GeV $m(\tilde{t}_1) = 50$ GeV $m(\tilde{t}_1) = 100$ GeV $m(\tilde{t}_1) = 500$ GeV $m(\tilde{t}_1) = 360$ GeV, $m(\tilde{b}_1) - m(\tilde{t}_1) = 40$ GeV	1708.09286, 1711.03301 1909.08457 1908.08122 ATLAS-CONF-2020-031 ATLAS-CONF-2020-003, 2004.14060 ATLAS-CONF-2019-017 1803.10178 1805.01649 1805.01649 1711.03301 SUSY-2018-09 SUSY-2018-09
	$\bar{t}\bar{t}, \bar{t} \rightarrow t\bar{t} \ell^0$	0 e, μ	Multiple	E_T^{miss}	36.1		$m(\tilde{t}_1) < 400$ GeV	1708.09286, 1711.03301
	$\bar{t}\bar{t}, \bar{t} \rightarrow t\bar{t} \ell^0$	0 e, μ	Multiple	E_T^{miss}	36.1		$m(\tilde{t}_1) < 400$ GeV	1708.09286, 1711.03301
	$\bar{t}\bar{t}, \bar{t} \rightarrow t\bar{t} \ell^0$	0-1 e, μ	2 b/2 γ	E_T^{miss}	139		$m(\tilde{t}_1) < 400$ GeV	ATLAS-CONF-2020-015 1911.12606
	$\bar{t}\bar{t}, \bar{t} \rightarrow t\bar{t} \ell^0$	2 e, μ	0 jets	E_T^{miss}	139		$m(\tilde{t}_1) < 400$ GeV	1908.08215
	$\bar{t}\bar{t}, \bar{t} \rightarrow t\bar{t} \ell^0$	0-1 e, μ	2 b/2 γ	E_T^{miss}	139		$m(\tilde{t}_1) < 400$ GeV	2004.10894, 1909.09226

*Only a selection of the available mass limits on new states or

ATLAS Exotics Searches* - 95% CL Upper Exclusion Limits

Status: May 2020

Model	ℓ, γ	Jets [†]	E_T^{miss}	$\int L dt$ [fb ⁻¹]	Limit	Reference		
Extra dimensions	ADD $G_{KK} + g/q$	0 e, μ	1-4 j	Yes	36.1	$M_{Pl} = 7.7$ TeV $M_s = 8.6$ TeV $M_{KK} = 8.9$ TeV $M_{KK} = 8.2$ TeV $M_{KK} = 9.55$ TeV	$n = 2$ $n = 3$ HLZ NLO $n = 6$ $n = 6, M_{Pl} = 3$ TeV, rot BH $n = 6, M_{Pl} = 3$ TeV, rot BH $k/M_{Pl} = 0.1$ $k/M_{Pl} = 1.0$ $\Gamma/m = 15\%$ Tier (1,1), $\mathcal{R}(A^{(1)} \rightarrow t\bar{t}) = 1$	1711.03301 1707.04147 1703.09127 1606.02265 1512.02586 1707.04147 1808.02380 2004.14636 1804.10823 1803.09678
	ADD non-resonant $\gamma\gamma$	2 γ	-	-	36.1			
	ADD CBH	-	≥ 2 j	-	37.0			
	ADD BH high Σp_T	≥ 1 e, μ	≥ 2 j	-	3.2			
	ADD BH multijet	-	≥ 3 j	-	3.6			
	RS1 $G_{KK} \rightarrow \gamma\gamma$	2 γ	-	-	36.1	G_{KK} mass 4.1 TeV G_{KK} mass 2.3 TeV G_{KK} mass 2.0 TeV		
	Bulk RS $G_{KK} \rightarrow WW/ZZ$	multi-channel	-	-	36.1			
	Bulk RS $G_{KK} \rightarrow WW \rightarrow \ell\nu q\bar{q}$	1 e, μ	2 j/1 j	Yes	139			
	Bulk RS $G_{KK} \rightarrow t\bar{t}$	1 e, μ	≥ 1 b, ≥ 1 ℓ	Yes	36.1			
	2UED / RPP	1 e, μ	≥ 2 j	Yes	36.1	KK mass 1.8 TeV		
Gauge bosons	SSM $Z' \rightarrow \ell\ell$	2 e, μ	-	-	139	Z' mass 5.1 TeV Z' mass 2.42 TeV Z' mass 2.1 TeV	$\Gamma/m = 1.2\%$	1903.06248 1709.07242 1805.09299
	SSM $Z' \rightarrow \tau\tau$	2 τ	-	-	36.1			
	Leptophobic $Z' \rightarrow b\bar{b}$	-	≥ 2 b	-	36.1			
	Leptophobic $Z' \rightarrow t\bar{t}$	0 e, μ	≥ 1 b, ≥ 2 j	Yes	139	Z' mass 4.1 TeV Z' mass 6.0 TeV		2005.05138 1906.05609 1801.06992
	SSM $W' \rightarrow \ell\nu$	1 e, μ	-	Yes	139	W' mass 3.7 TeV W' mass 4.3 TeV		2004.14636 1905.08559
	SSM $W' \rightarrow \tau\nu$	1 τ	-	Yes	36.1			
	HVT $W' \rightarrow WZ \rightarrow \ell\nu q\bar{q}$ model B	1 e, μ	2 j/1 j	Yes	139	W' mass 3.8 TeV W' mass 2.93 TeV		1712.06518 CERN-EP-2020-073
	HVT $W' \rightarrow WH/ZH$ model B	0 e, μ	2 j	-	139	W' mass 3.2 TeV W' mass 3.25 TeV		1807.10473 1904.12679
	HVT $W' \rightarrow WH$ model B	0 e, μ	≥ 1 b, ≥ 2 j	Yes	139	W' mass 5.0 TeV		
	LRSW $W_R \rightarrow t\bar{b}$	0 e, μ	1 j	-	80			
CI	CI $\ell\ell q\bar{q}$	-	2 j	-	37.0	A 21.8 TeV A 35.8 TeV	$ C_{41} = 4\pi$ $ C_{41} = 4\pi$	1703.09127 CERN-EP-2020-066 1811.02305
	CI $\ell\ell q\bar{q}$	2 e, μ	-	-	139			
	CI $t\bar{t}t\bar{t}$	≥ 1 e, μ	≥ 1 b, ≥ 1 j	Yes	36.1	A 2.57 TeV		
DM	Axial-vector mediator (Dirac DM)	0 e, μ	1-4 j	Yes	36.1	\tilde{m}_{DM} 1.55 TeV \tilde{m}_{DM} 1.67 TeV	$g_s = 0.25, g_b = 1.0, m(\chi) = 1$ GeV $g = 1.0, m(\chi) = 1$ GeV $m(\chi) < 150$ GeV $\gamma = 0.4, \lambda = 0.2, m(\chi) = 10$ GeV	1711.03301 1711.03301 1602.02372 1812.07343
	Colored scalar mediator (Dirac DM)	0 e, μ	1-4 j	Yes	36.1	\tilde{m}_{DM} 700 GeV		
	VV $\chi\chi$ EFT (Dirac DM)	0 e, μ	1, 4, ≥ 1 j	Yes	3.2			
	Scalar reson. $\phi \rightarrow t\bar{t}$ (Dirac DM)	0-1 e, μ	1 b, 0-1 j	Yes	36.1	ϕ mass 3.4 TeV		
LQ	Scalar LQ 1 st gen	1, 2 e	≥ 2 j	Yes	36.1	LQ mass 1.4 TeV LQ mass 1.56 TeV	$\beta = 1$ $\beta = 1$	1902.00377 1902.00377
	Scalar LQ 2 nd gen	1, 2 e	≥ 2 j	Yes	36.1	LQ mass 1.03 TeV	$\mathcal{B}(LQ_s^+ \rightarrow b\tau) = 1$ $\mathcal{B}(LQ_s^+ \rightarrow \tau) = 0$	1902.08103 1902.08103
	Scalar LQ 3 rd gen	2 τ	2 b	-	36.1			
	Scalar LQ 3 rd gen	0-1 e, μ	2 b	Yes	36.1	LQ mass 970 GeV		
Heavy quarks	VLQ $TT \rightarrow Ht/Zt/Wb + X$	multi-channel	-	-	36.1	T mass 1.37 TeV B mass 1.34 TeV	$SU(2)$ doublet $SU(2)$ doublet $\mathcal{B}(T_{3/3} \rightarrow Wt) = 1, c(\mathcal{B}_{3/3} Wt) = 1$ $\mathcal{B}(Y \rightarrow Wb) = 1, c(\mathcal{B}_{3/3} Wb) = 1$ $x_B = 0.5$	1808.02343 1808.02343 1801.11883

Measurements, searches, and global fit: a statistical perspective

Measurement

- What is usually called a “measurement” can be defined as **parameter estimation** within the SM hypothesis
- This quantifies precisely “what you see” (SM), but says nothing about “what you do not see” (NP)
- Used to extract SM inputs to searches and global fits

Search (or direct search)

- This usually refers to “direct searches” where, through a statistical **hypothesis test**, the SM gets confronted with an alternative hypothesis
- It gives some information on how much your data prefer the SM vs a well defined alternative model

Fit (or global fit or indirect search)

- This consists of either **parameter estimation** beyond the SM or a **hypothesis test** with a general enough alternative hypothesis (e.g. EFT)
- It gives information on “what you see” and “what you do not see”
- Notice that only BSM parameters are fit, while SM ones are taken from **measurements**

The (HL-)LHC legacy

“BSM measurements” (aka global fit v2.0: SM+EFT)

- It is known that uncertainties on some SM inputs is what limits the extraction of BSM parameters and, conversely, the presence of NP may affect extraction of SM parameters

Examples: PDFs vs DY, multi-jet vs α_S , etc.

- As the knowledge of the SM increases (better predictions and more analyses become available) and the large EFT parameter space gets a “good coverage” (several channels are measured and can be combined with each others) one can build a combined likelihood of SM+EFT
- Analyses that were targeting direct searches need to be turned into “measurements”, which require a higher level of precision (e.g. di-bosons)
- A simple (and interesting) example could be given by fitting EFT and PDF together using DY data

The LHC legacy (in ~20 years) is to design and accomplish the final BSM measurement (which includes SM!)

(New) Challenges

- **Combination and correlation:** combining experimental analyses is still a big issue at the LHC, where uncertainties are parametrized differently and correlations are not known (there is a slow progress but huge work ahead)
- **Defining observables:** observables related to precision measurements are often targeted at “SM measurements”. It is necessary to extend and optimize them towards multi-differential “BSM measurement” oriented observables (e.g. recent triple differential DY cross section)
- **Large parameter space:** when the number of parameters $>$ a few, many studies become unfeasible (a lot of work in this direction: MEM, ML techniques, MadMiner, analytic reweighting, etc.)
- **EFT in backgrounds:** EFT effects may be relevant, especially for reducible BGs
- **Theory errors:** a further complication arises when statistical uncertainties become “negligible” and theory errors start to dominate (e.g. missing HO). Including theory errors in statistical analysis presents conceptual issues that need to be addressed
- **Result presentation:** not only experimental analyses, but also theory results are still shown in an ad-hoc and incomplete way (e.g. 2D contours, etc). For experiments the issue is more severe, but theorists should try to get used to always deliver the full likelihood leading to their fit, that could be used by others and as inputs to global fits

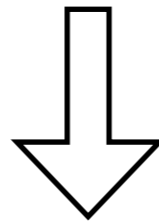
Still a long way to go, but the path is clear

The EFT direction(s)

EFT for the SM seems like a rather “new” topic for theorists

Many theorists have abandoned model building in favor of EFT

This is not a psychological effect due to the absence of new physics



Absence of new physics (and the existence of precision measurements) is a requirement for EFT to be interesting, relevant and applicable!

EFT is the simplest and most consistent way of parametrizing the different directions in which deviations from the SM can appear (SM deformations)

It is incredibly powerful at determining what “is possible”, what “is impossible”, what “is likely” and what “is unlikely”

Measurements (and especially precision measurements) in high energy physics have little meaning if one cannot quantify the above in a consistent way

In other words, EFT provides the “alternative hypothesis” necessary for a statistical hypothesis test of the SM

Precision: LHC vs LEP

Compare for instance LEP and LHC sensitivity to an interaction of the form

Z-pole observable

$$-\frac{\hat{S}}{4m_W^2} (H^\dagger \tau^a H) W_{\mu\nu}^a B^{\mu\nu}$$

LEP

LHC

Energy: ~100 GeV

Energy: ~1 TeV

Accuracy: ~‰-‰

Accuracy: ~10%

New physics effects not enhanced by energy

New physics effects not enhanced by energy

LHC cannot compete with LEP

off Z-pole observable

$$-\frac{Y}{4m_W^2} (\partial_\rho B_{\mu\nu})^2$$

LEP

LHC

Energy: ~100 GeV

Energy: ~1 TeV

Accuracy: ~‰-‰

Accuracy: ~10%

New physics effects not enhanced by energy

New physics effects enhanced by

$$E_{\text{LHC}}^2 / E_{\text{LEP}}^2 \sim 100$$

LHC comparable with (or better than) LEP

Generalization of this reasoning is what defines the high pT LHC precision program

State of the art

➤ Drell-Yan (neutral and charged)

(aka quark-quark-lepton-lepton four fermion interactions)

De Blas et al., 1307.5068

Alioli et al., 1712.02347

RT et al., 2008.12978

Farina et al., 1609.08157

Fuentes-Martin et al., 2003.12421

➤ Di-jets and multi-jets (and inclusive jet)

(aka 4quark four fermion interactions)

Alioli et al., 1706.03068

➤ Di-tops

(aka 2quark-2t four fermion interactions)

Farina et al., 1811.04084

➤ Di-bosons (including VH)

Biekötter et al., 1406.7320

Baglio et al., 1708.03332

Grojean et al., 1810.05149

Falkowski et al. 1508.00581

Panico et al., 1708.07823

Henning et al., 1812.09299

Butter et al., 1604.03105

Franceschini et al. 1712.01310

Ethier et al., 2101.03180

Zhang, 1610.0618

Liu et al., 1804.08688

Green et al., 1610.07572

Banerjee et al., 1807.01796

Conclusions

- The (HL)-LHC legacy may be given by “BSM measurements” which extend the concepts of SM measurement, NP search, and global fit
- There are several issues to be addressed (precise theory predictions, combination of experimental analyses, definition of observables, large parameter space and signal generation, EFT in backgrounds, treatment of TH uncertainties, etc.) but the path is clear
- LHC has the unique opportunity of doing precision in the high- p_T region, which allows to set unprecedented constraints on a large class of EFT operators
- The high- p_T precision program is a clear BSM direction complementary to (on-shell) Higgs properties and “low energy” precision (Z-pole EW, flavour, etc.)
- Some results already exist for DY, di-jet, $t\bar{t}$, dibosons, but this only consists of a handful of studies and most of the work has yet to be done

THANK YOU

BACKUP

Precision in DY at LHC

DY@LHC profits of great precision (is the most precise channel at LHC)

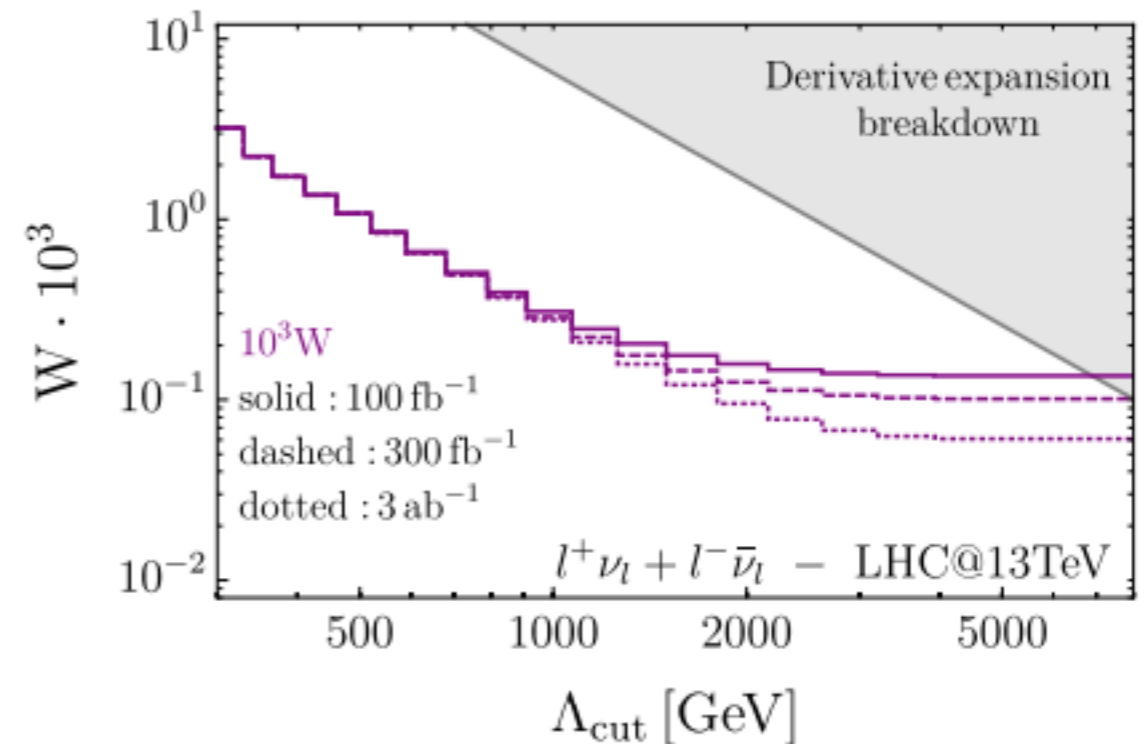
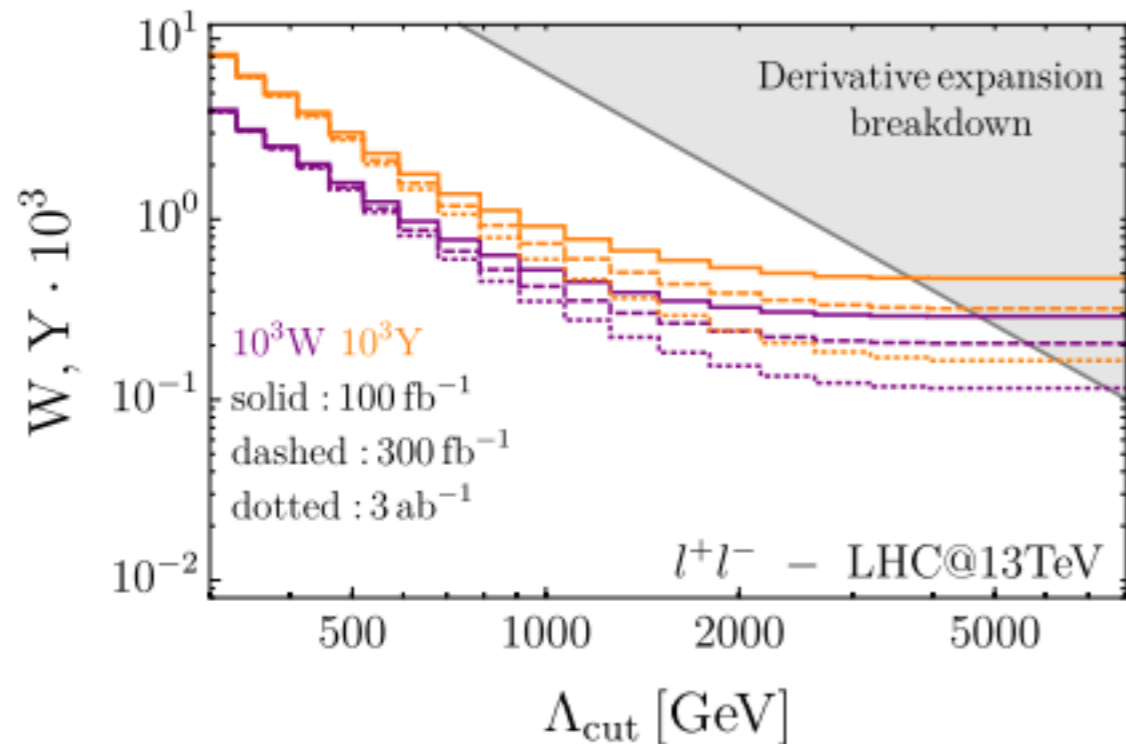
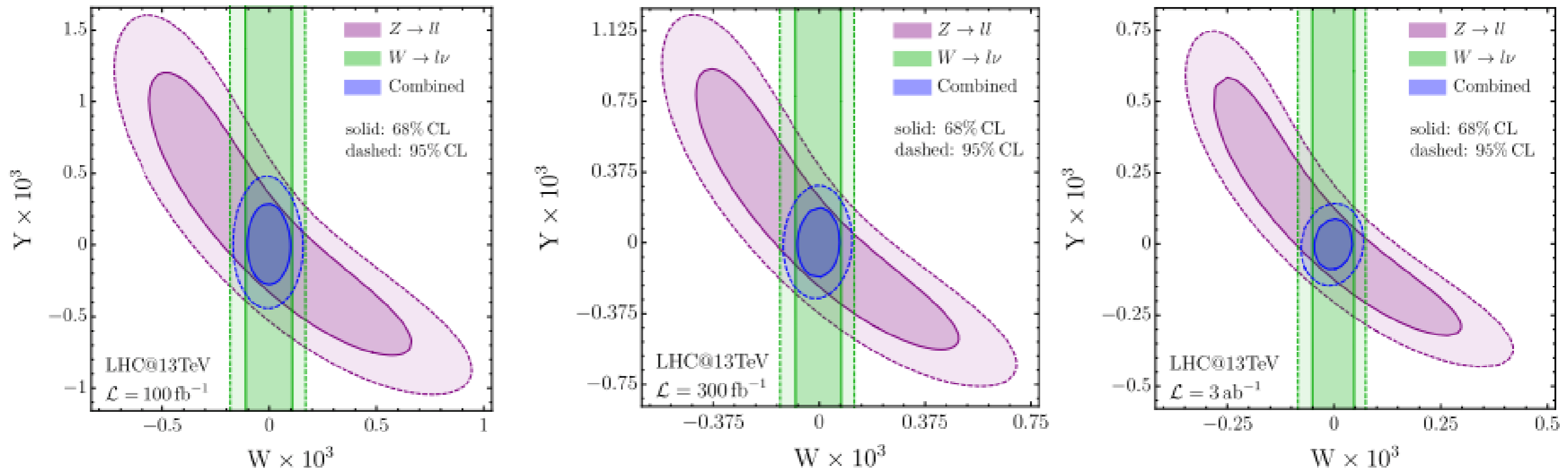
- LHC few percent experimental (statistic/systematic) uncertainties
- NLO QCD+NLO EW theory calculation (e.g. POWHEG)
- NNLO QCD theory calculation (e.g. FEWZ)
- NNLO PDFs (both MC ensembles and Hessian reduction)
- NP contributions (from qqll current-current operators) factorize with respect to QCD corrections and leading-log EW corrections
- This means that signal events can be generated including QCD and EW corrections with a simple analytic reweighting and do not require any scan over EFT parameters

Generic current-current
$O_{lq}^{(3)} = (\bar{l}_L \sigma_I \gamma^\mu l_L)(\bar{q}_L \sigma_I \gamma_\mu q_L),$
$O_{lq}^{(1)} = (\bar{l}_L \gamma^\mu l_L)(\bar{q}_L \gamma_\mu q_L),$
$O_{eu} = (\bar{e}_R \gamma^\mu e_R)(\bar{u}_R \gamma_\mu u_R),$
$O_{ed} = (\bar{e}_R \gamma^\mu e_R)(\bar{d}_R \gamma_\mu d_R),$
$O_{lu} = (\bar{l}_L \gamma^\mu l_L)(\bar{u}_R \gamma_\mu u_R),$
$O_{ld} = (\bar{l}_L \gamma^\mu l_L)(\bar{d}_R \gamma_\mu d_R),$
$O_{qe} = (\bar{q}_L \gamma^\mu q_L)(\bar{e}_R \gamma_\mu e_R)$

W&Y current-current
$O'_{2W} = J_L^{a,\mu} J_{L,\mu}^a, \quad J_L^{a,\mu} = \sum_f \bar{f} \gamma^\mu T^a f,$
$O'_{2B} = J_Y^\mu J_{Y,\mu}, \quad J_Y^\mu = \sum_f \bar{f} \gamma^\mu Y f,$
$G_{lq}^{(3)} = \frac{1}{2} G'_{2W},$
$G_{lq}^{(1)} = -\frac{1}{6} G'_{2B}, \quad G_{eu} = -\frac{4}{3} G'_{2B},$
$G_{ed} = \frac{2}{3} G'_{2B}, \quad G_{lu} = -\frac{2}{3} G'_{2B},$
$G_{ld} = \frac{1}{3} G'_{2B}, \quad G_{qe} = -\frac{1}{3} G'_{2B}$

Precision in DY at LHC: W&Y

RT et al., 2008.12978



Precision in di-jet at LHC: Z

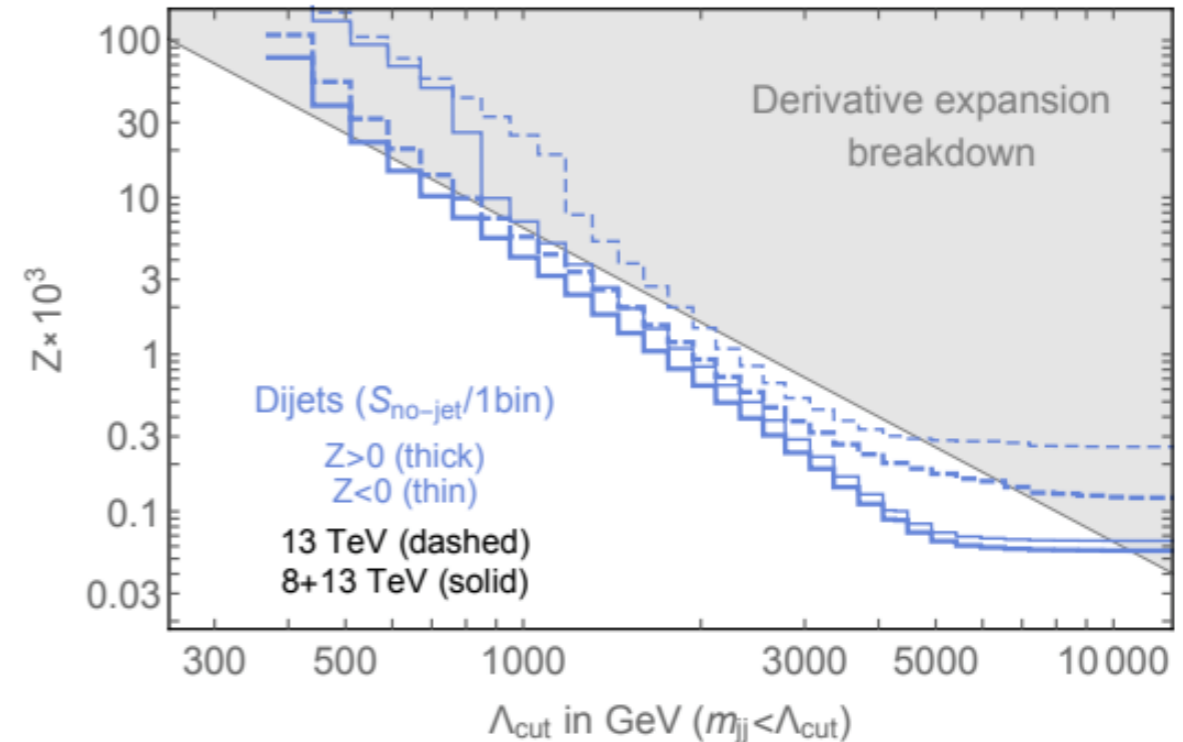
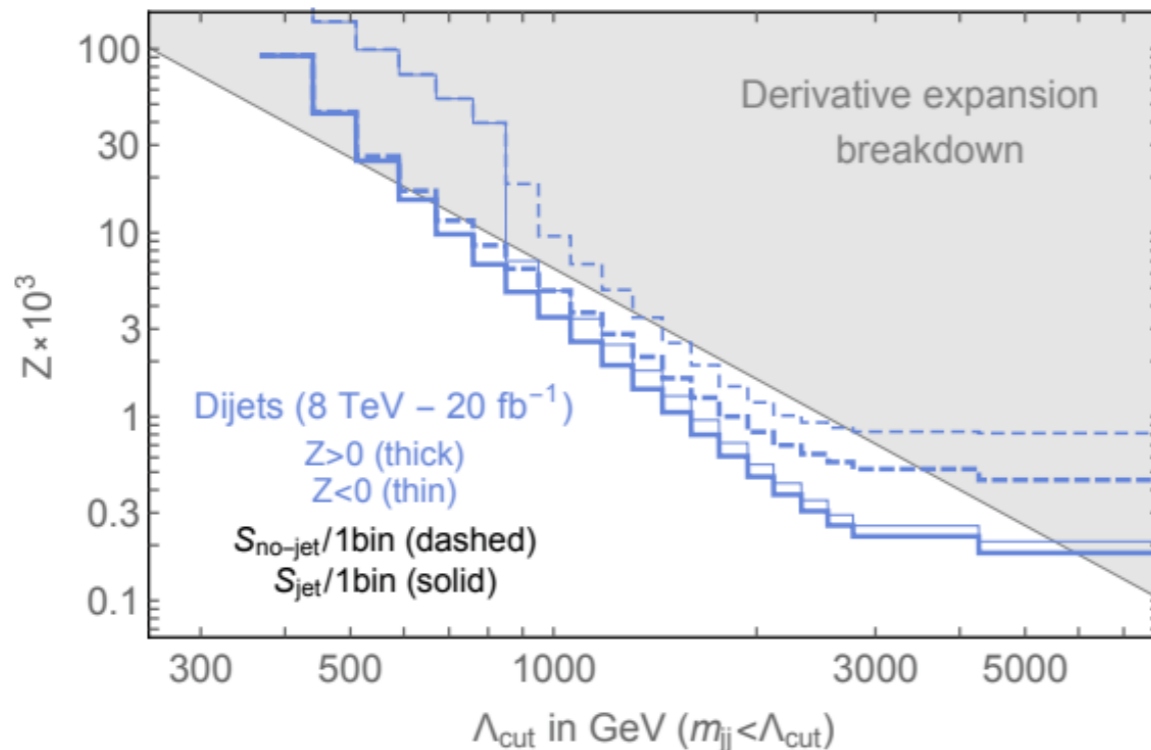
95% CL bounds on $Z \times 10^4$ for $\sqrt{s} = 8$ TeV

Alioli et al., 1712.02347

Analysis	$\mathcal{S}_{\text{no-jet}} - 1\text{bin}$	$\mathcal{S}_{\text{no-jet}} - 2\text{bins}$	$\mathcal{S}_{\text{jet}} - 1\text{bin}$
dijet	[-9.4,+4.9]	[-2.6,+2.1]	[-2.1,+1.8]
inclusive jet	[-13.8,+4.2]	[-2.5,+2.3]	[-2.7,+2.1]

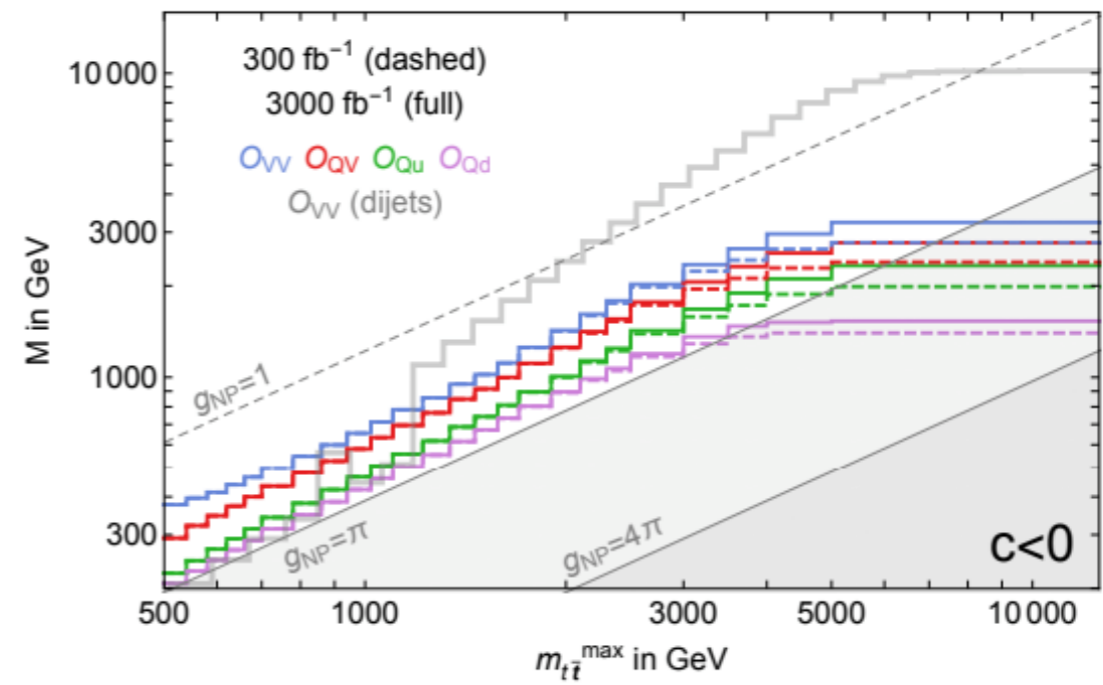
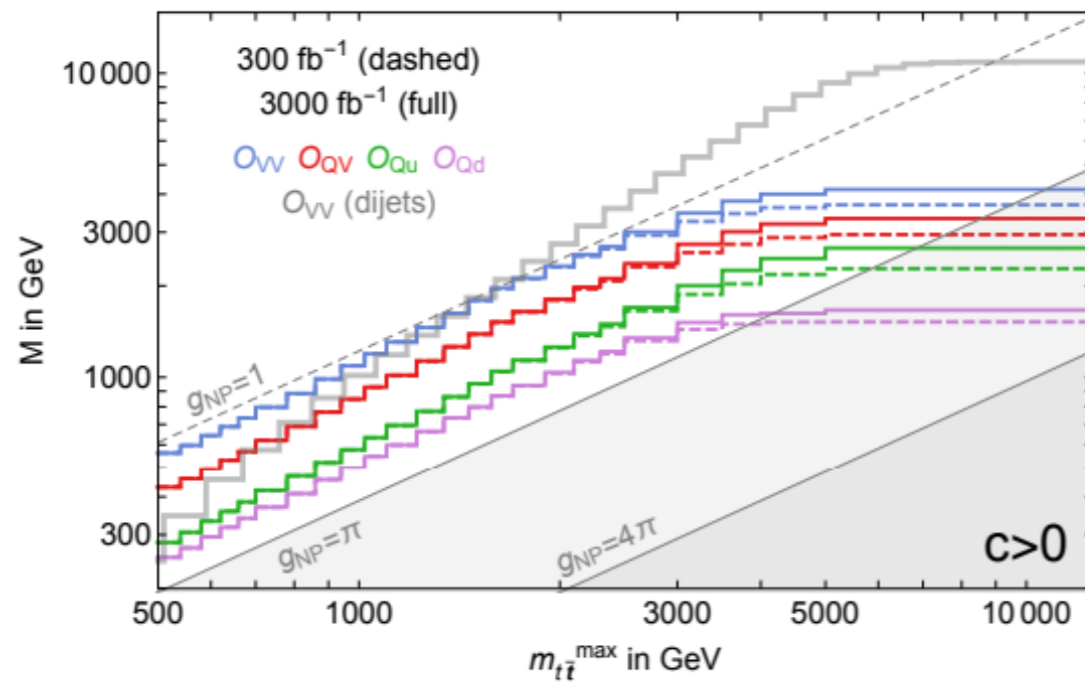
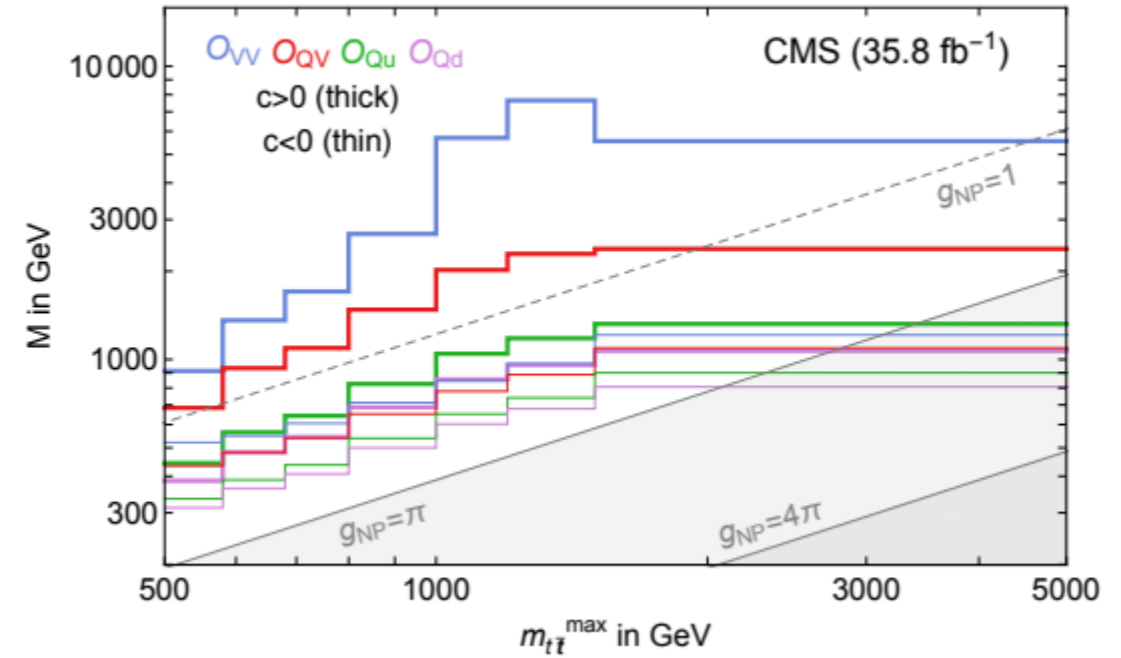
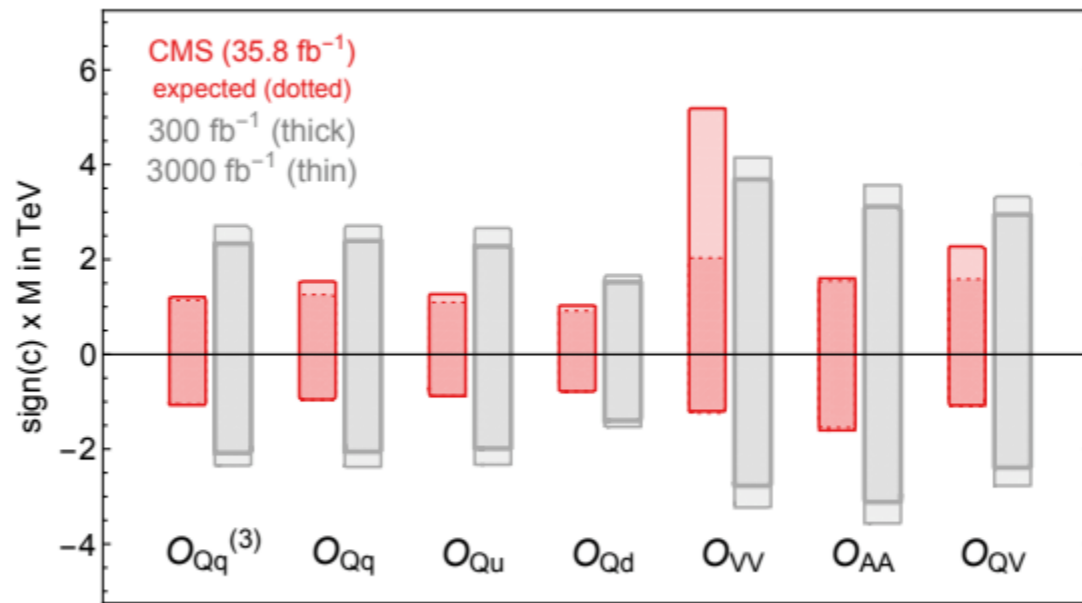
95% CL bounds on $Z \times 10^4$ for $\sqrt{s} = 13, 100$ TeV

Analysis	\sqrt{s} - Luminosity	$\mathcal{S}_{\text{no-jet}} - 1\text{bin}$	$\mathcal{S}_{\text{no-jet}} - 2\text{bins}$	$\mathcal{S}_{\text{jet}} - 1\text{bin}$
dijet	13 TeV - 40 fb ⁻¹	[-3.3,+1.7]	[-1.0,+0.9]	[-0.8,+0.7]
	13 TeV - 0.3 ab ⁻¹	[-3.1,+1.4]	[-0.7,+0.6]	[-0.6,+0.5]
	13 TeV - 3 ab ⁻¹	[-2.8,+1.2]	[-0.5,+0.4]	[-0.5,+0.5]
	100 TeV - 10 ab ⁻¹	$[-4.5,+2.5] \times 10^{-2}$	$[-2.4,+1.7] \times 10^{-2}$	$[-1.4,+1.2] \times 10^{-2}$
inclusive jet	13 TeV - 40 fb ⁻¹	[-5.0,+1.5]	[-1.0,+0.9]	[-1.0,+0.8]
	13 TeV - 0.3 ab ⁻¹	[-4.2,+1.1]	[-0.7,+0.6]	[-0.7,+0.6]
	13 TeV - 3 ab ⁻¹	[-3.5,+0.9]	[-0.5,+0.5]	[-0.6,+0.5]
	100 TeV - 10 ab ⁻¹	$[-10.7,+2.6] \times 10^{-2}$	$[-1.6,+1.4] \times 10^{-2}$	$[-1.9,+1.5] \times 10^{-2}$



Precision in $t\bar{t}b\bar{a}r$ at LHC

Farina et al., 1811.04084



Precision in di-bosons at LHC

Franceschini et al., 1712.01310

SILH Basis

$$\mathcal{O}_W = \frac{ig}{2} \left(H^\dagger \sigma^a \overleftrightarrow{D}^\mu H \right) D^\nu W_{\mu\nu}^a$$

$$\mathcal{O}_B = \frac{ig'}{2} \left(H^\dagger \overleftrightarrow{D}^\mu H \right) \partial^\nu B_{\mu\nu}$$

$$\mathcal{O}_{HW} = ig(D^\mu H)^\dagger \sigma^a (D^\nu H) W_{\mu\nu}^a$$

$$\mathcal{O}_{HB} = ig'(D^\mu H)^\dagger (D^\nu H) B_{\mu\nu}$$

$$\mathcal{O}_{2W} = -\frac{1}{2} (D^\mu W_{\mu\nu}^a)^2$$

$$\mathcal{O}_{2B} = -\frac{1}{2} (\partial^\mu B_{\mu\nu})^2$$

Example of constraint on a BSM “high-energy primary” from WZ

$$A_{u-\bar{d}_+}^{hW^+} = A_{u-\bar{d}_+}^{ZW^+} = A_{d-\bar{u}_+}^{hW^-} = -A_{d-\bar{u}_+}^{ZW^-} = \sqrt{2}a_q^{(3)}$$

$$a_q^{(3)} = \frac{g^2}{M^2} (c_W + c_{HW} - 2c_{2W}) = -\frac{g^2}{m_W^2} (c_{\theta_W}^2 \delta g_1^Z + W)$$

