Misure da fare a LHC nel 2018 e oltre …

DEC. 1 2017

ROBERTO FRANCESCHINI (ROMA 3 UNIVERSITY)

ROMA TRE UNIVERSITÀ DEGLI STUDI

RLM Rita Levi Montalcini

Riunione Nazionale CMS Italia - Piacenza

Is LHC the new LEP?

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Outline

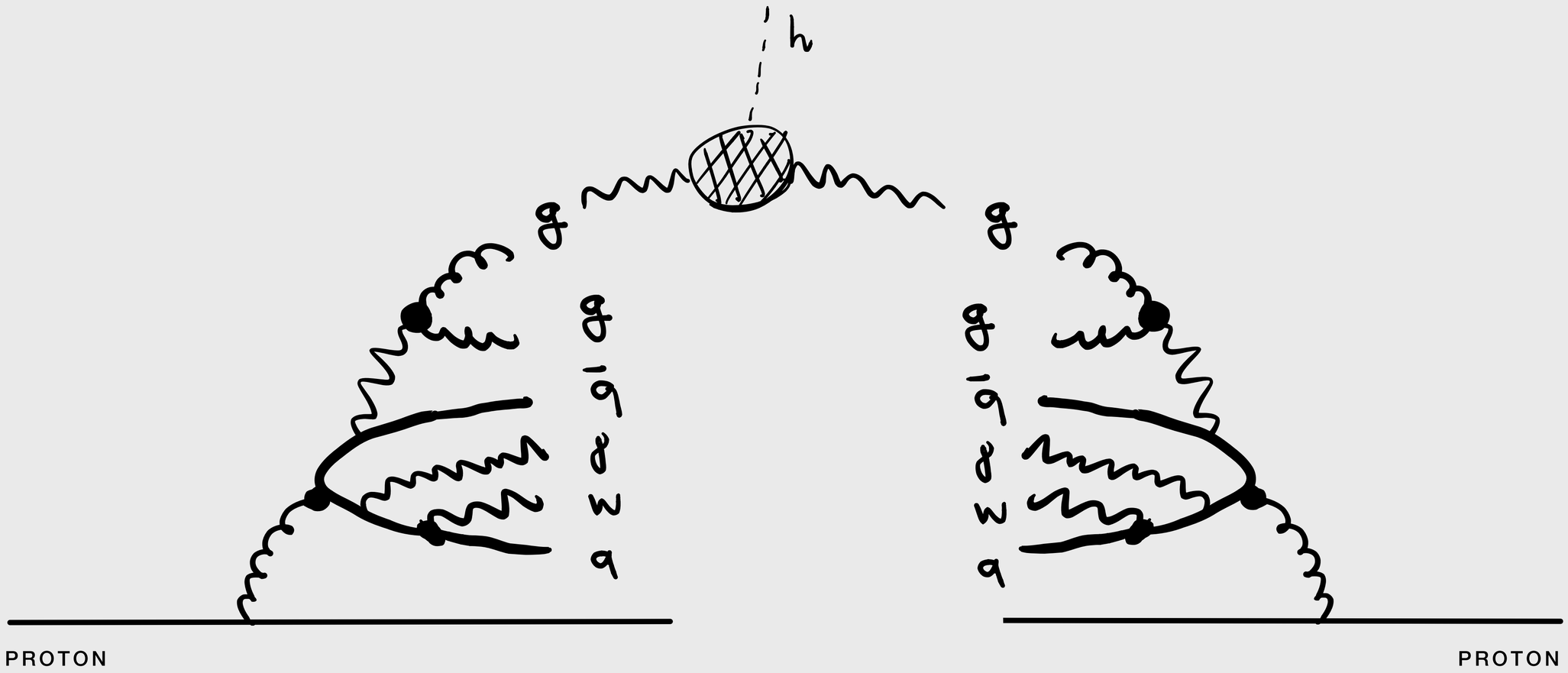
- What the LHC was supposed to find
- What we are currently dealing with
- What we could do in 2035

LHC: a direct investigation of open questions on the Standard Model

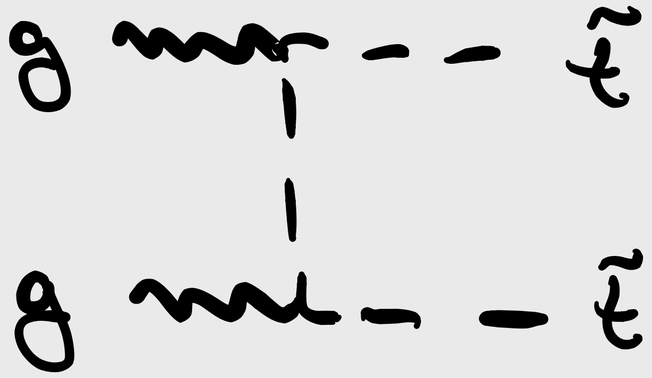
EXPLORE FUNDAMENTAL INTERACTIONS

- What is the origin of the scale of weak interactions?
- Is there a dynamical origin for the parameters of the SM?
- Can we explain what 95% of the Universe is made of?

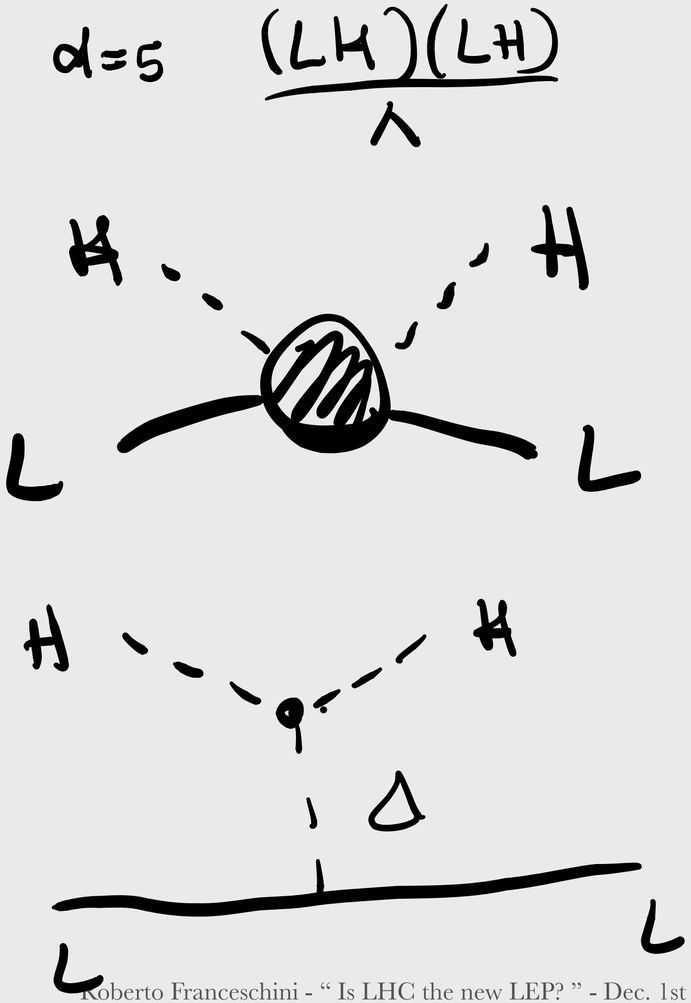
Direct Production

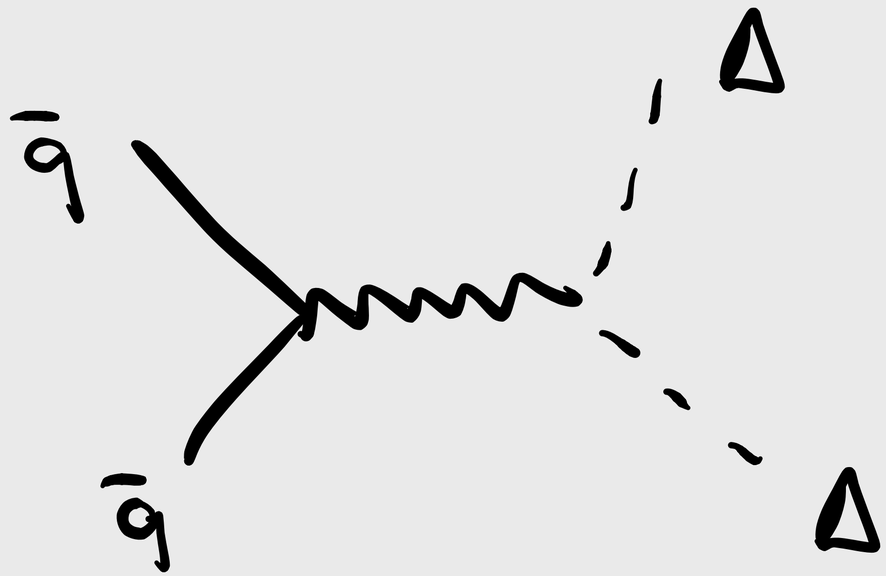


Direct Production



Direct Production





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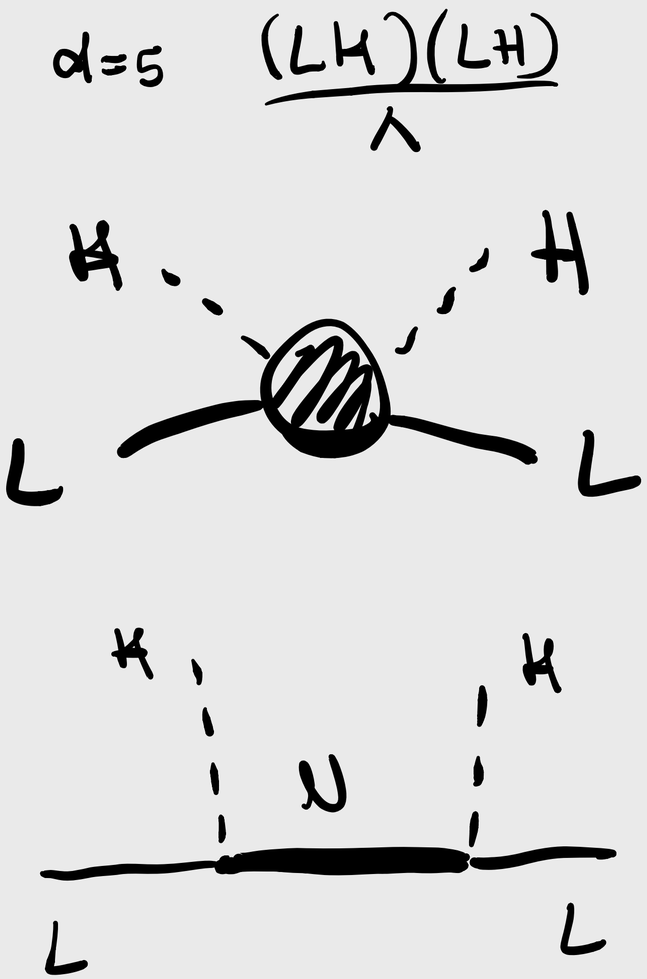
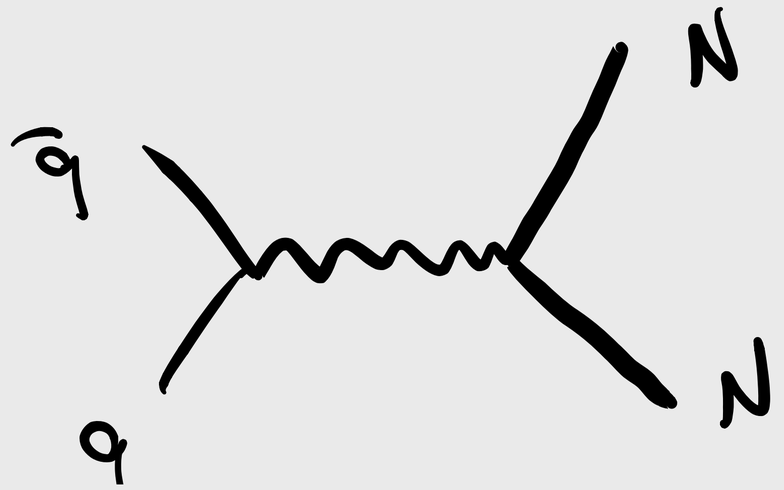
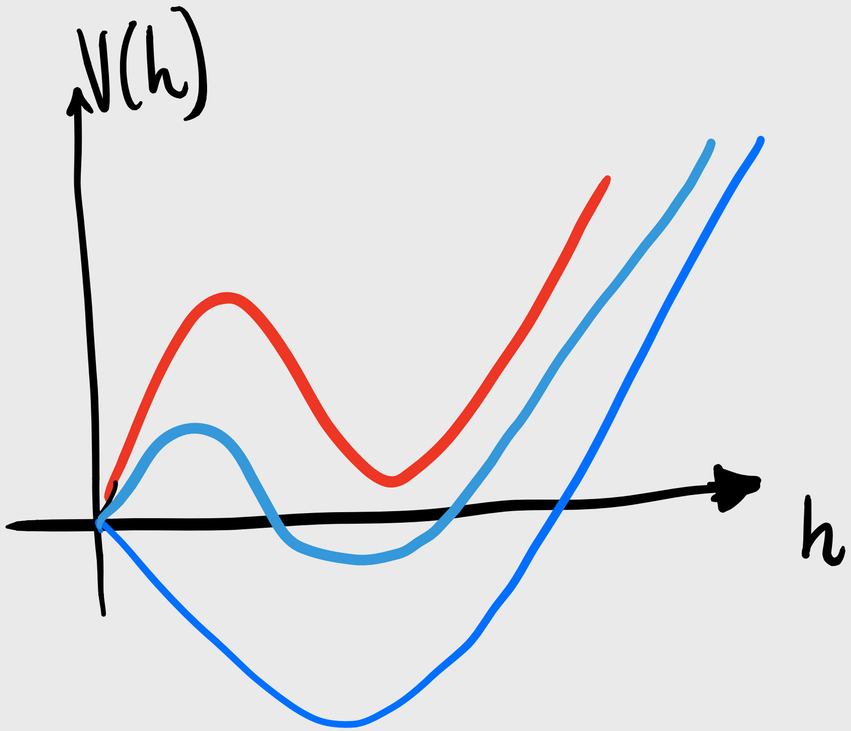
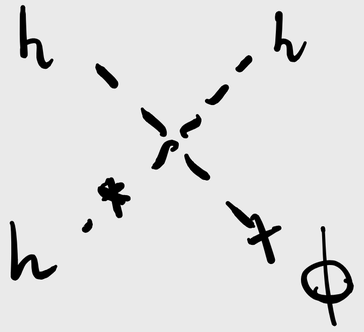




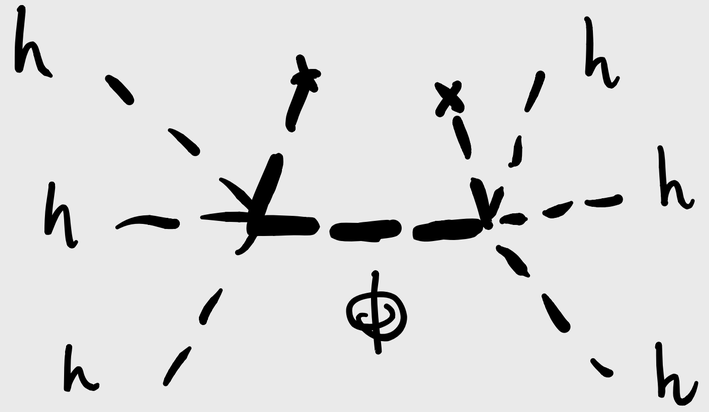
Direct Production

$$V(h) = \mu^2 h^2 + \lambda h^4 + \delta V$$

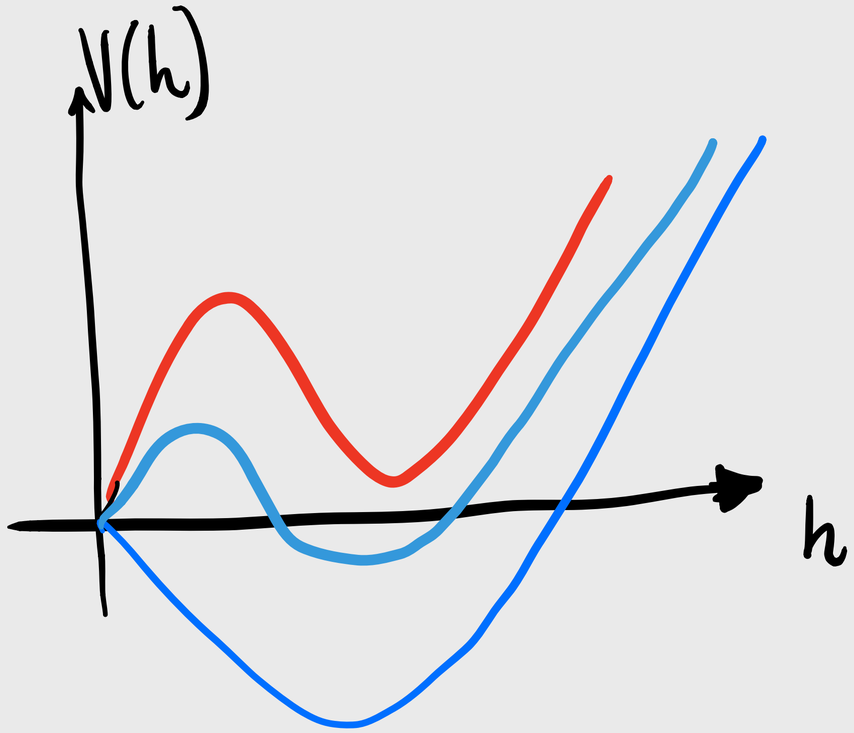


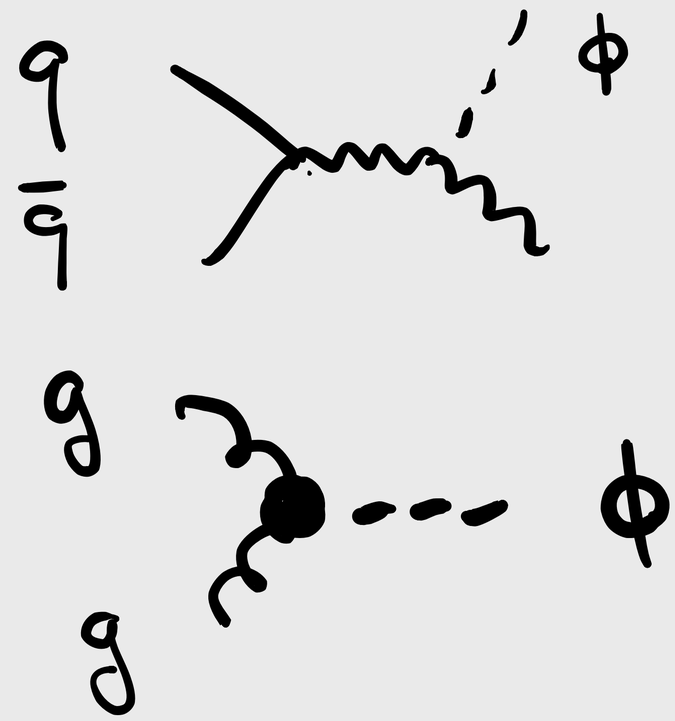


$$\mu^2 \phi^2 \xrightarrow{\text{mix}} h_1^3 \phi \xrightarrow{\text{SSB}} h_1^3 \langle \phi \rangle$$



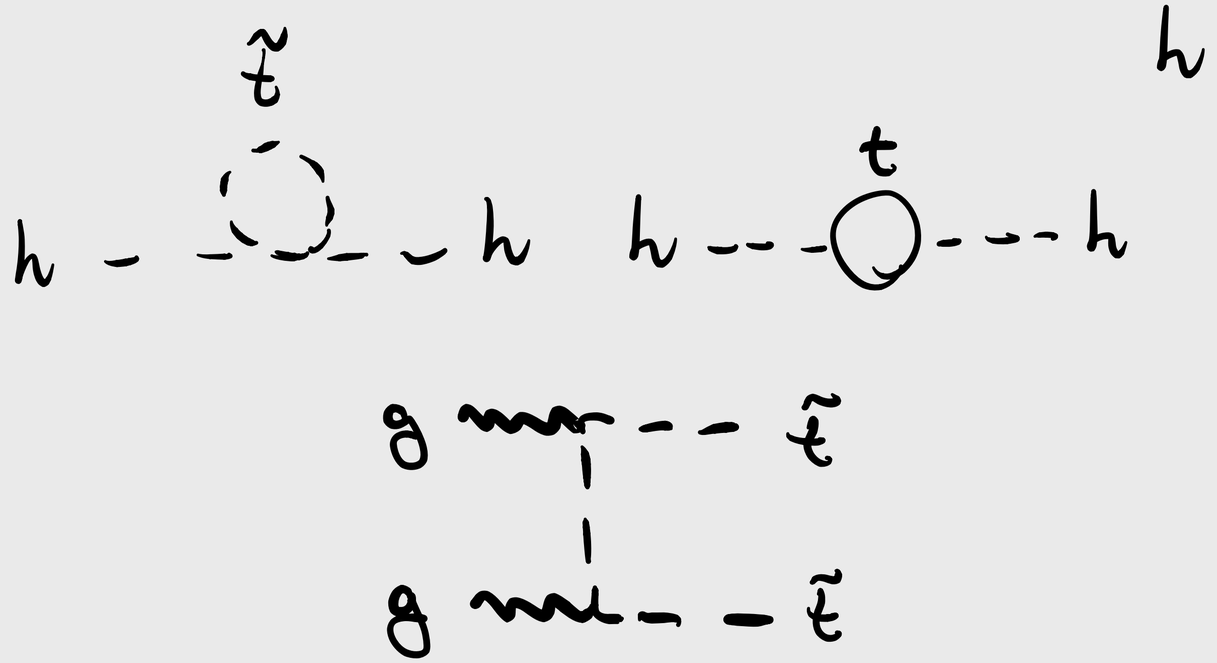
Direct Production





2012

$m_h = 125\,\text{GeV}$



2012-

$m_{new} = 0.1\text{-}10\,\text{TeV}$

2012

$m_h = 125\,GeV$

2012 -

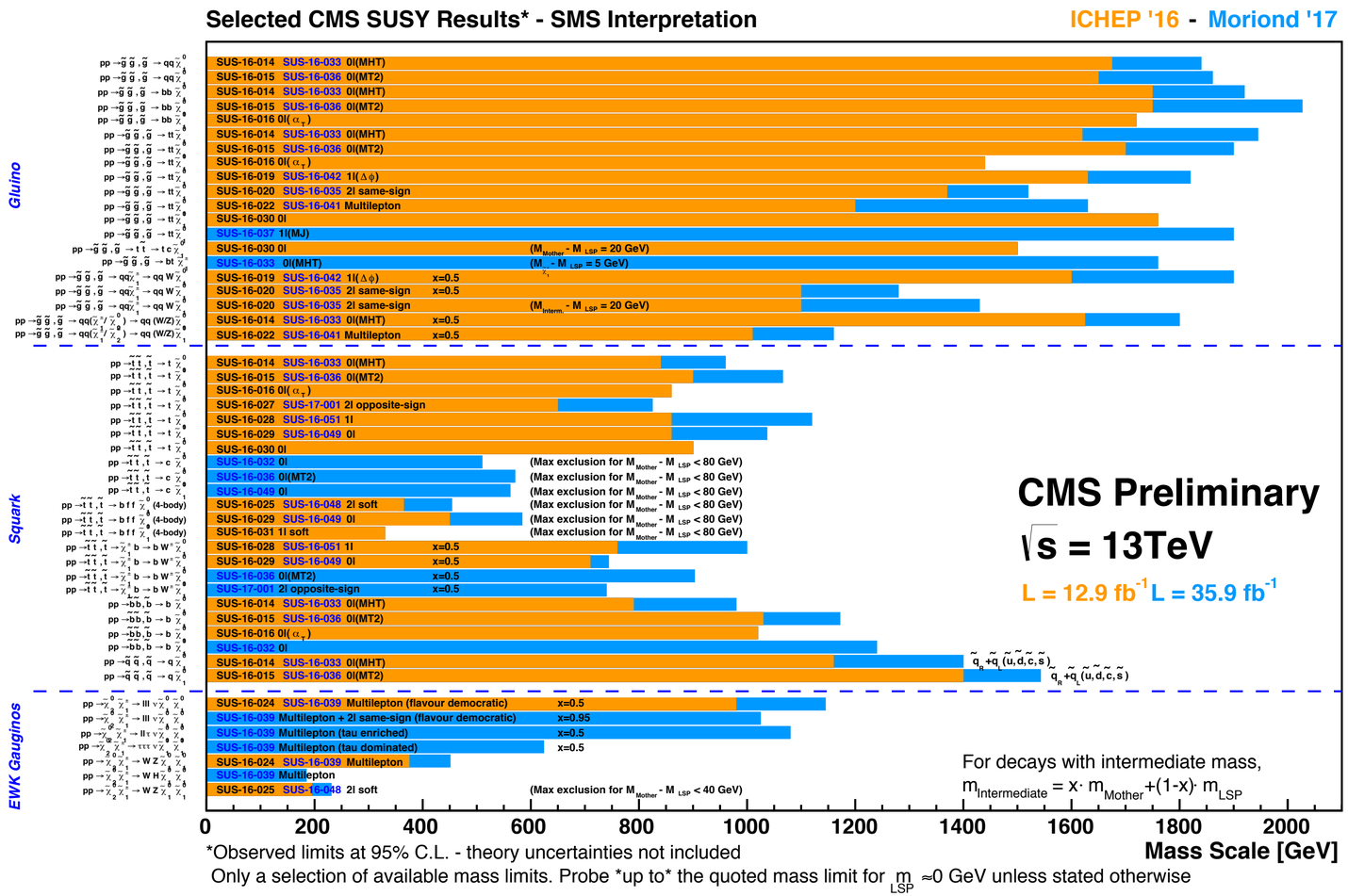
$m_{new} = 0.1\text{-}10\,TeV$

2012

$m_h = 125\ GeV$

2012 -

$m_{new} = 0.1\text{-}10\ TeV$



2012

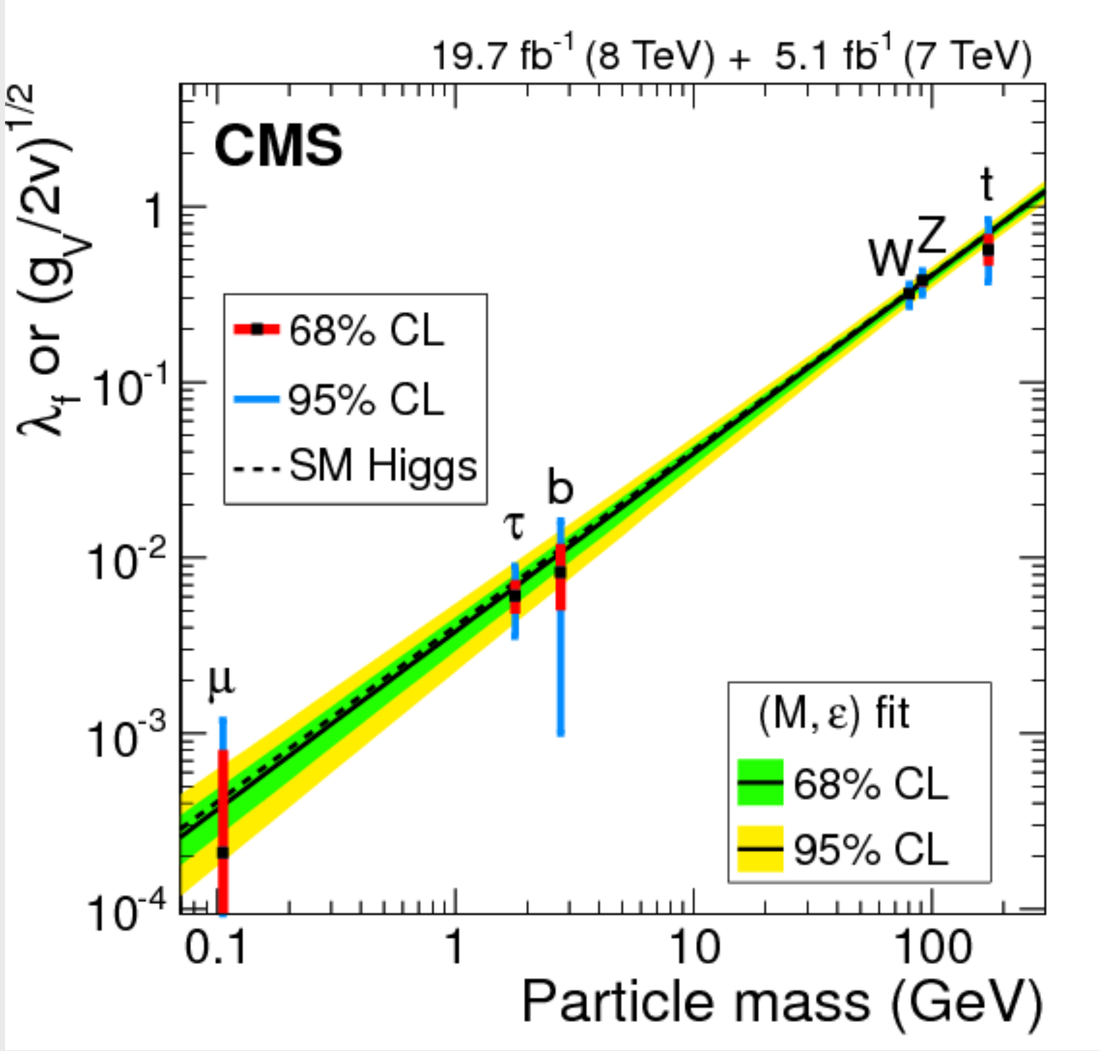
$m_h = 125\,GeV$

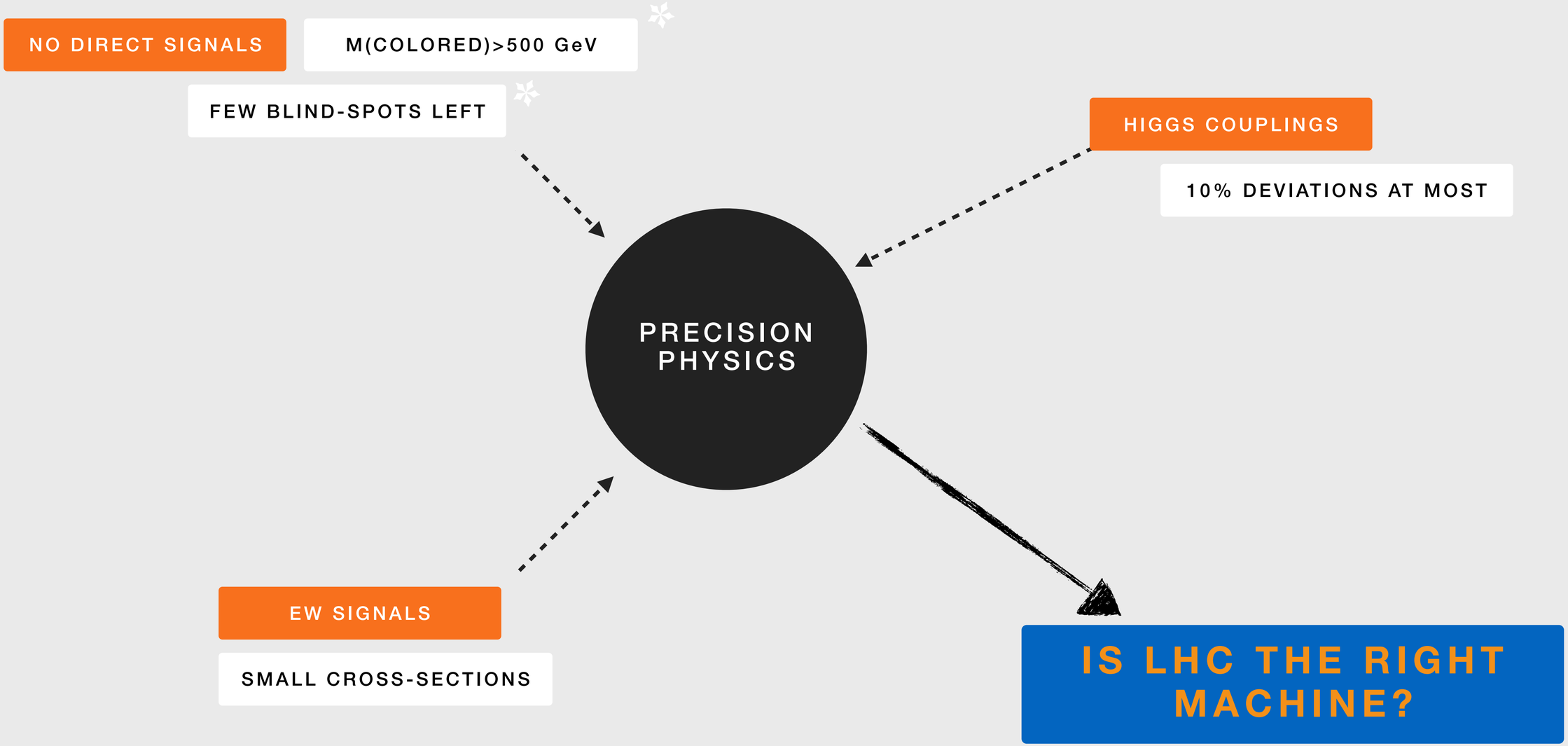
2012-

$m_{new} = 0.1\text{-}10\,TeV$

2014-

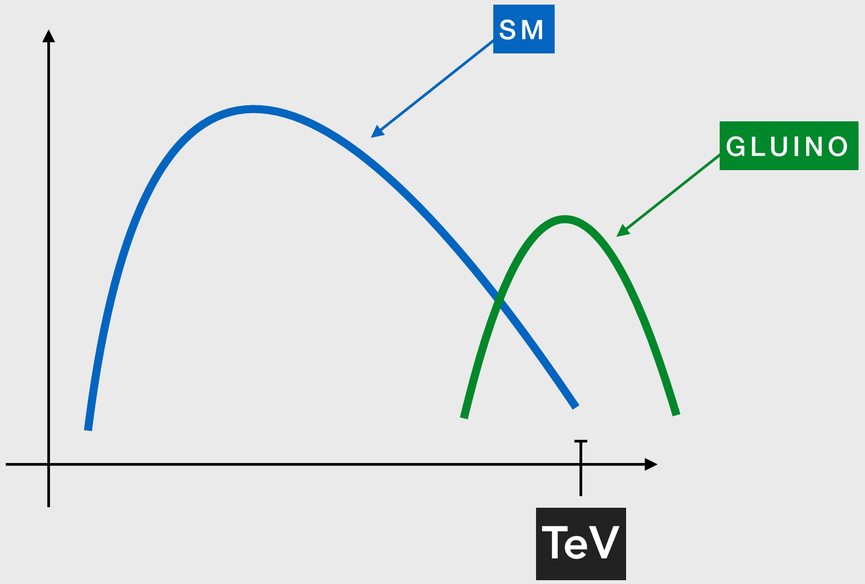
$g_h / g_{hSM} \simeq 1 \pm 0.1$

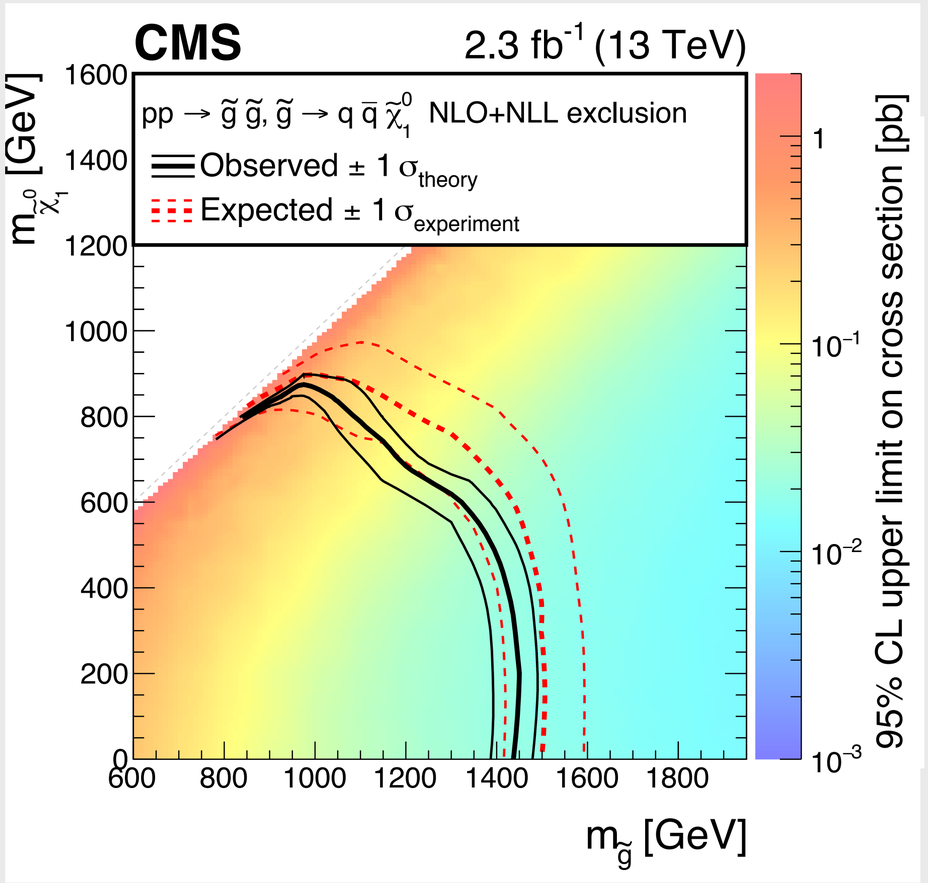



NO DIRECT SIGNALS
M(COLORED)>500 GeV
FEW BLIND-SPOTS LEFT
HIGGS COUPLINGS
10% DEVIATIONS AT MOST
PRECISION PHYSICS
EW SIGNALS
SMALL CROSS-SECTIONS
IS LHC THE RIGHT MACHINE?

LHC signals

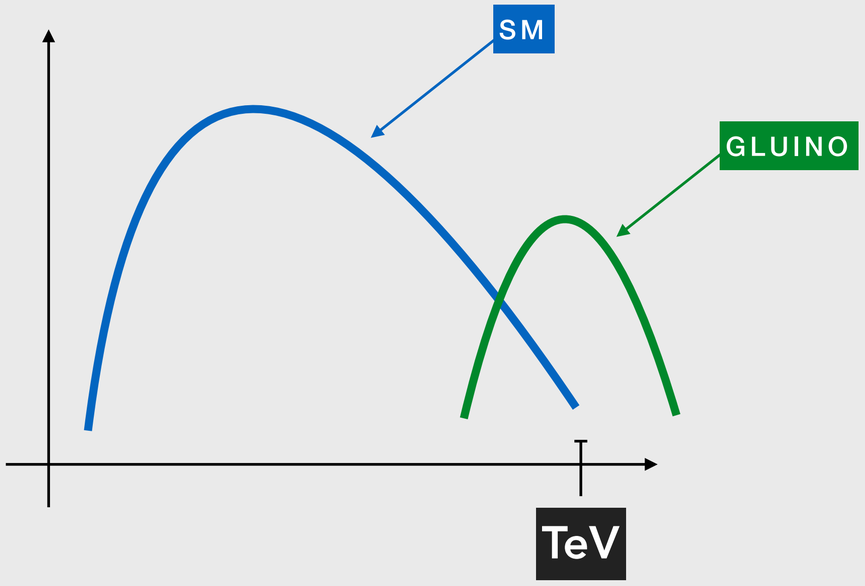
SEARCHES IN FINAL STATES : HARD LEPTONS+PHOTONS+JETS+MET



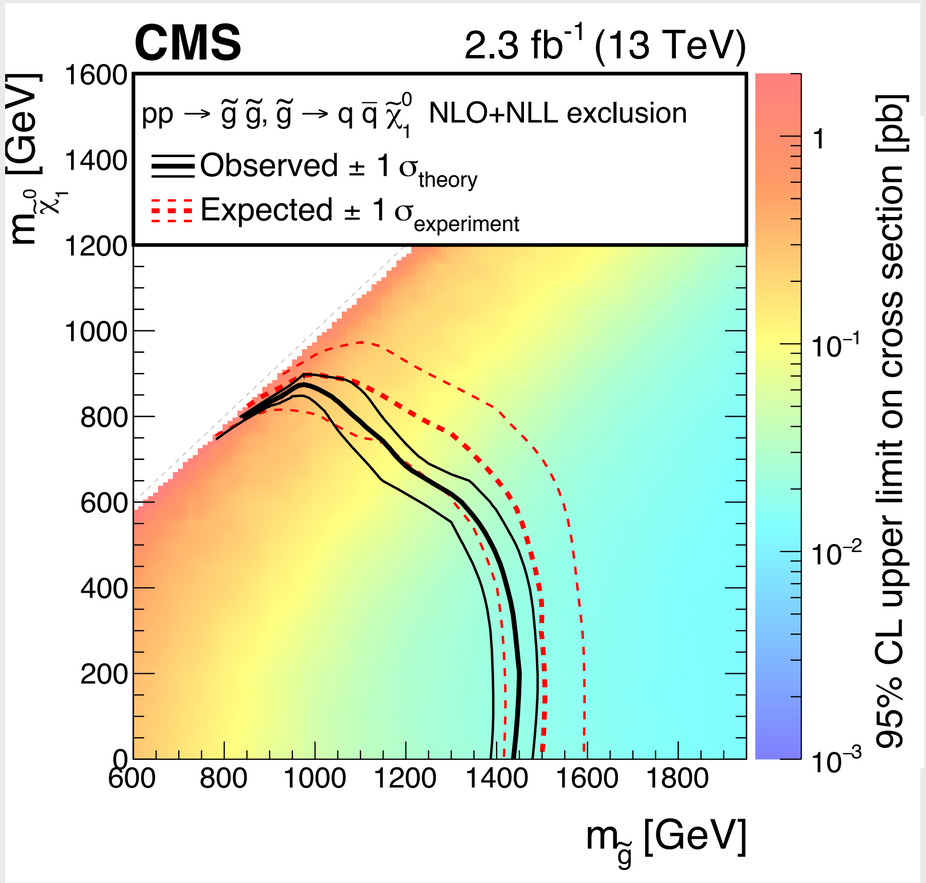


LHC signals

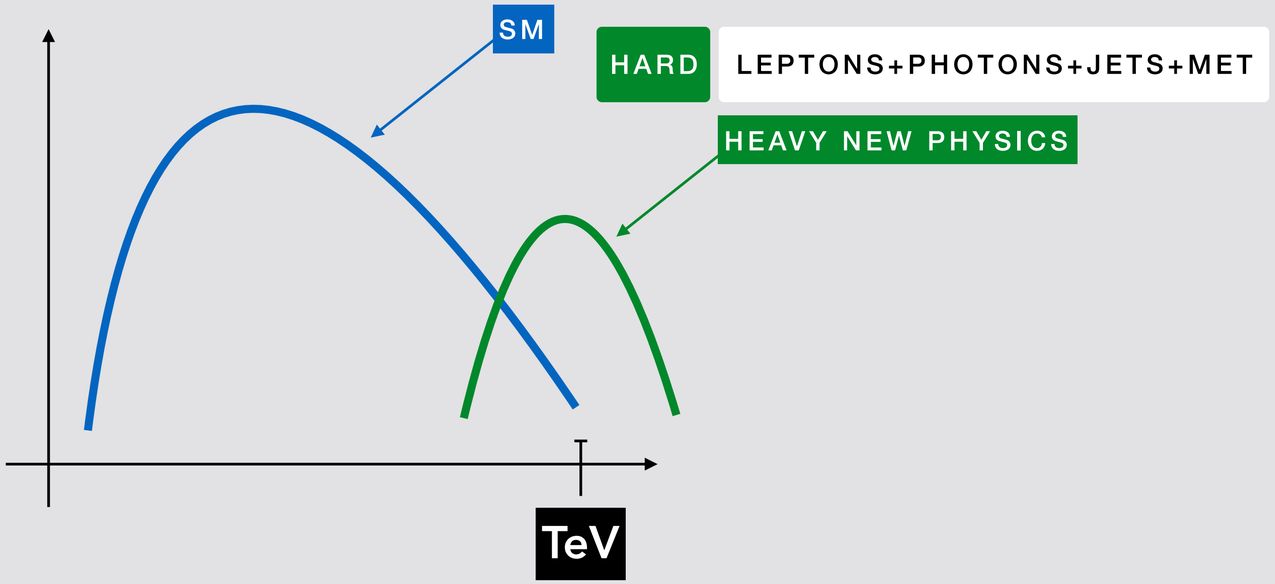
SEARCHES IN FINAL STATES : HARD LEPTONS+PHOTONS+JETS+MET

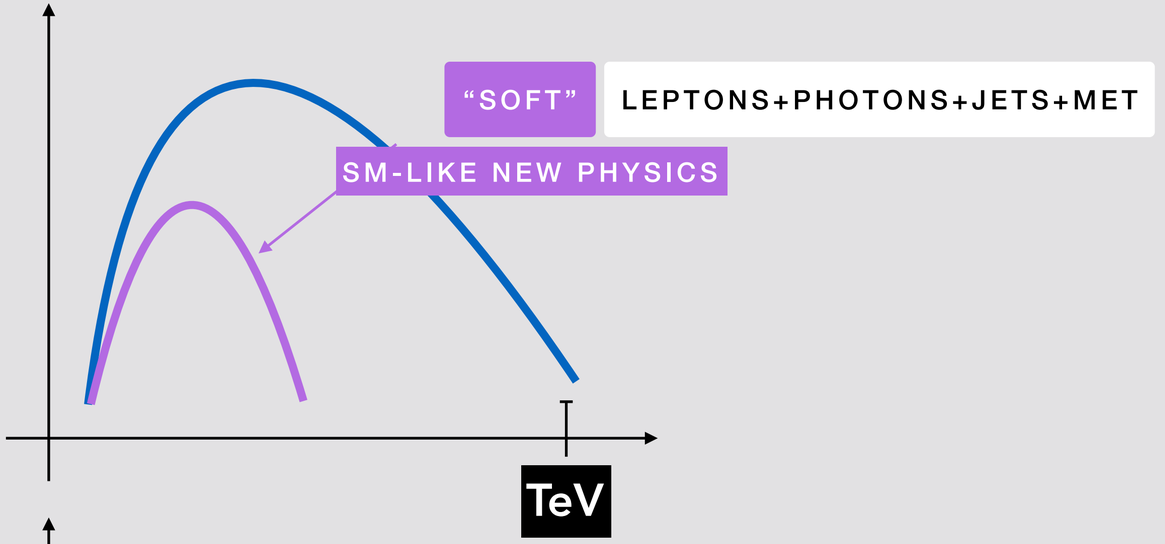


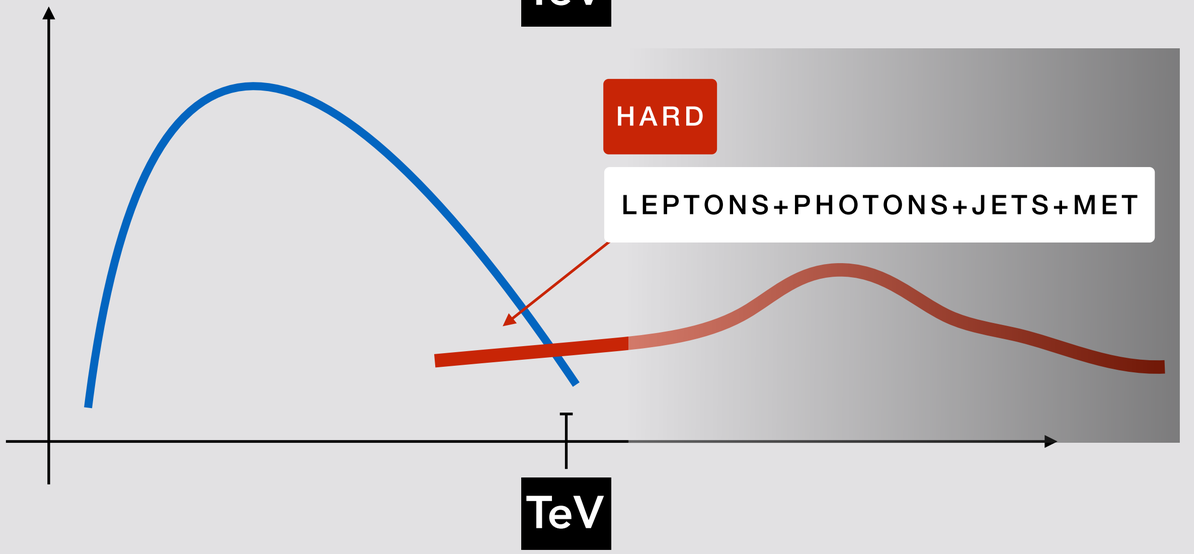
large S/B



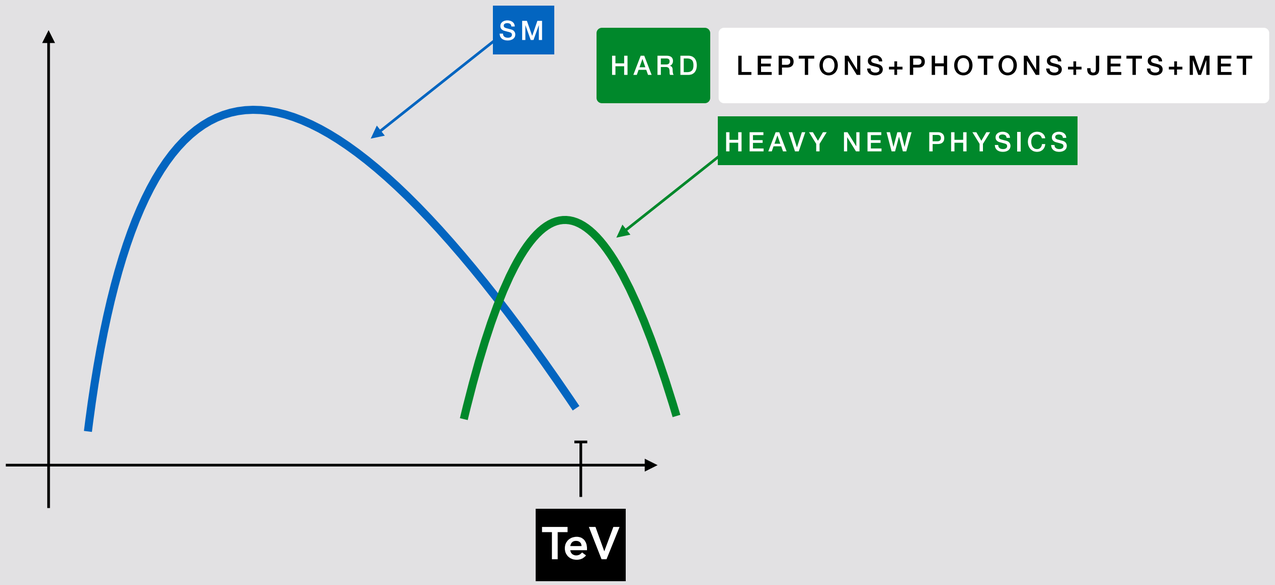
LHC signals


SM
HARD
LEPTONS+PHOTONS+JETS+MET
HEAVY NEW PHYSICS
TeV

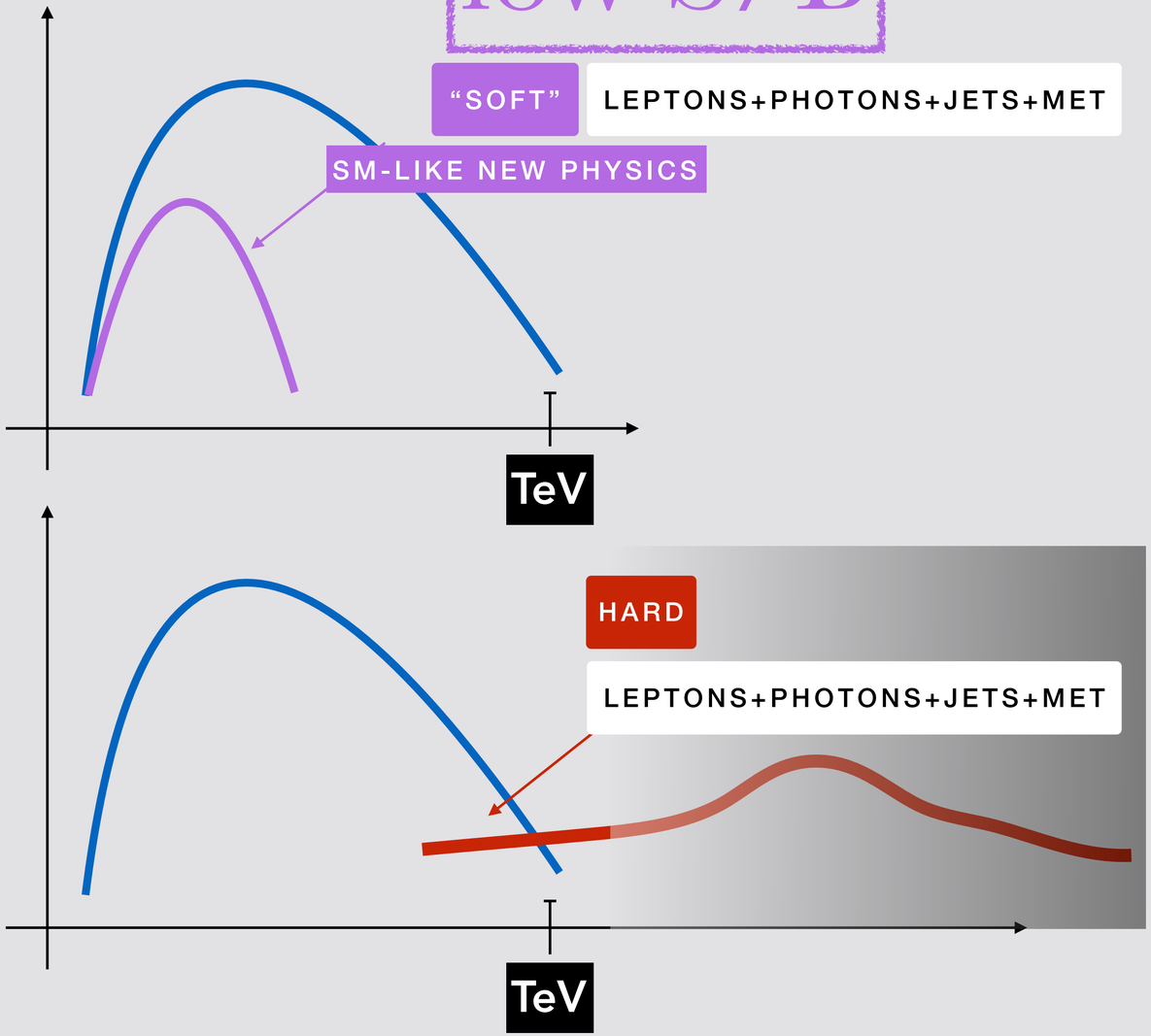

“SOFT”
LEPTONS+PHOTONS+JETS+MET
SM-LIKE NEW PHYSICS
TeV


HARD
LEPTONS+PHOTONS+JETS+MET
TeV

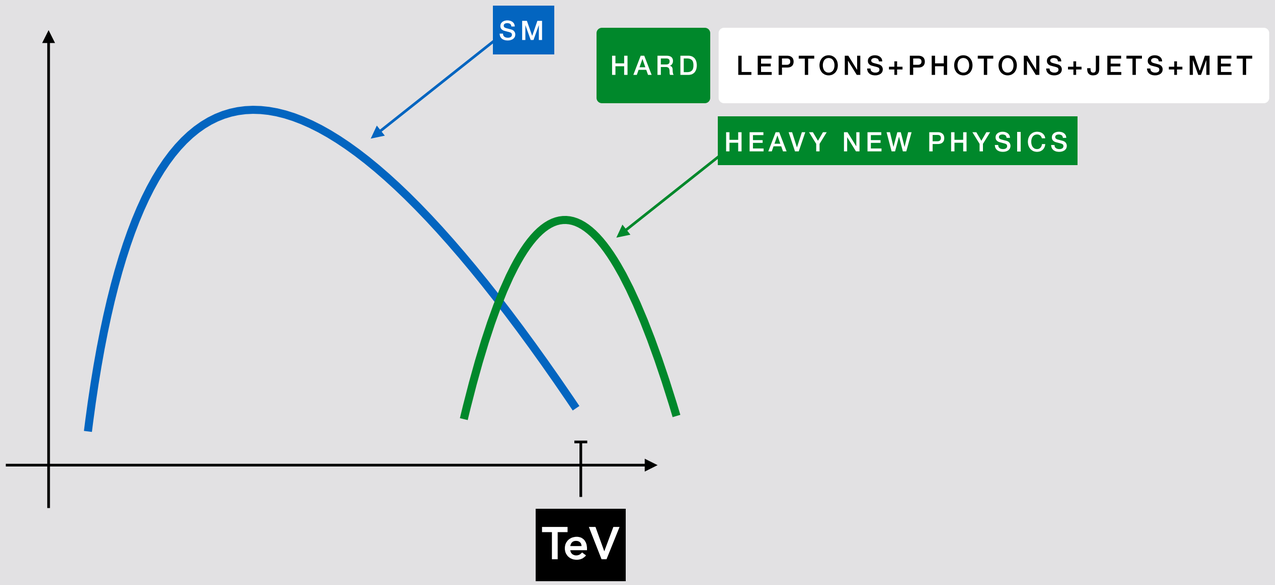
LHC signals



low S/B



LHC signals



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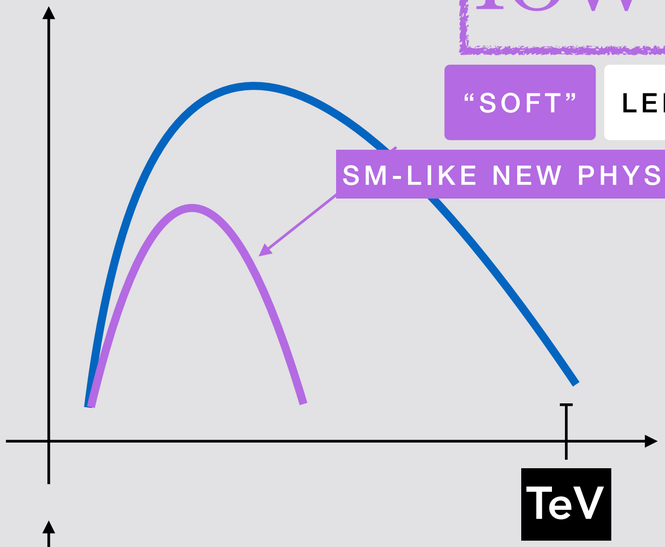
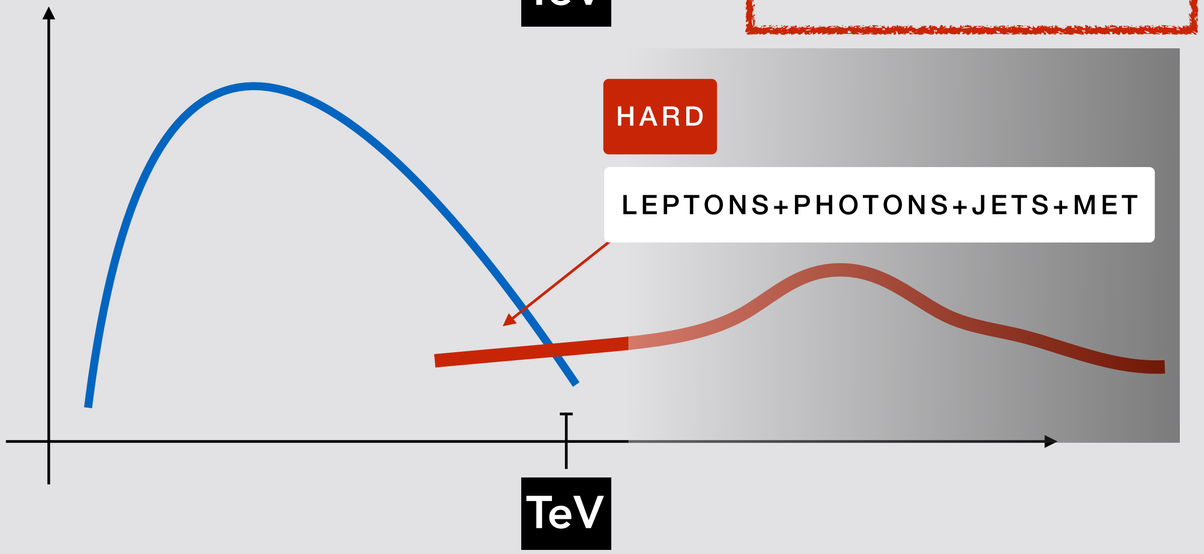
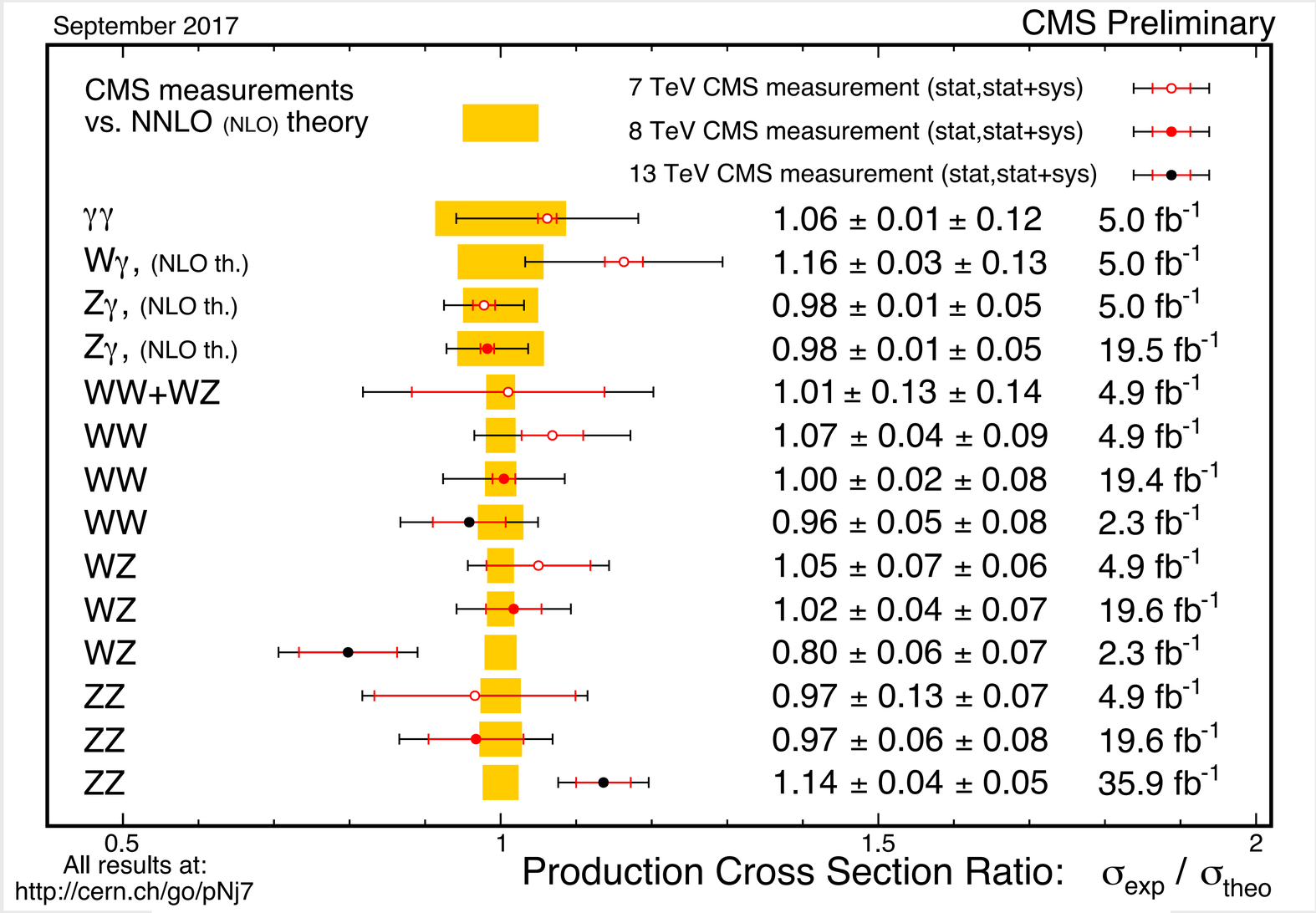
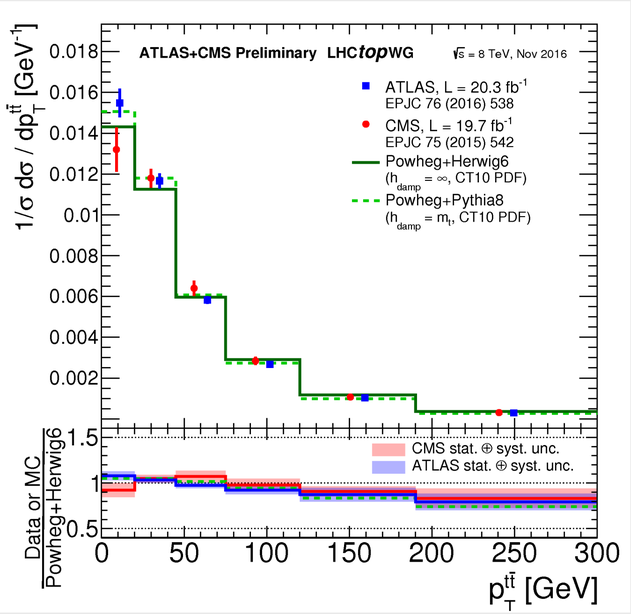
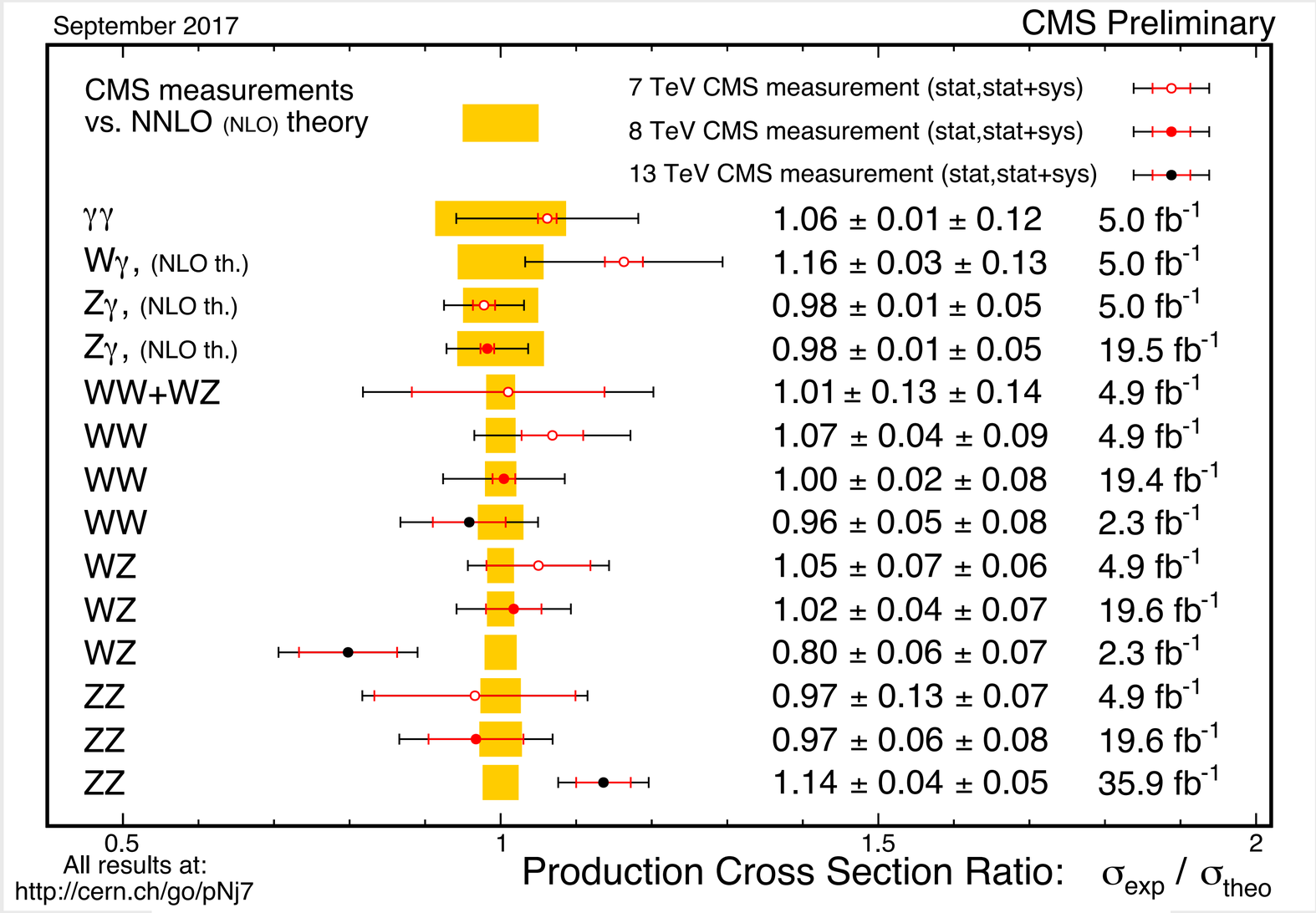


low S/B




September 2017
CMS Preliminary
CMS measurements
vs. NNLO (NLO) theory
7 TeV CMS measurement (stat,stat+sys)
8 TeV CMS measurement (stat,stat+sys)
13 TeV CMS measurement (stat,stat+sys)
γγ 1.06 ± 0.01 ± 0.12 5.0 fb-1
Wγ, (NLO th.) 1.16 ± 0.03 ± 0.13 5.0 fb-1
Zγ, (NLO th.) 0.98 ± 0.01 ± 0.05 5.0 fb-1
Zγ, (NLO th.) 0.98 ± 0.01 ± 0.05 19.5 fb-1
WW+WZ 1.01 ± 0.13 ± 0.14 4.9 fb-1
WW 1.07 ± 0.04 ± 0.09 4.9 fb-1
WW 1.00 ± 0.02 ± 0.08 19.4 fb-1
WW 0.96 ± 0.05 ± 0.08 2.3 fb-1
WZ 1.05 ± 0.07 ± 0.06 4.9 fb-1
WZ 1.02 ± 0.04 ± 0.07 19.6 fb-1
WZ 0.80 ± 0.06 ± 0.07 2.3 fb-1
ZZ 0.97 ± 0.13 ± 0.07 4.9 fb-1
ZZ 0.97 ± 0.06 ± 0.08 19.6 fb-1
ZZ 1.14 ± 0.04 ± 0.05 35.9 fb-1
0.5
1
1.5
2
All results at:
http://cern.ch/go/pNj7
Production Cross Section Ratio: σexp / σtheo


ATLAS+CMS Preliminary LHCtopWG
√s = 8 TeV, Nov 2016
ATLAS, L = 20.3 fb-1
EPJC 76 (2016) 538
CMS, L = 19.7 fb-1
EPJC 75 (2015) 542
Powheg+Herwig6
(hdamp = ∞, CT10 PDF)
Powheg+Pythia8
(hdamp = mt, CT10 PDF)
1/σ dσ / dpTtt [GeV-1]
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
CMS stat. ⊕ syst. unc.
ATLAS stat. ⊕ syst. unc.
Data or MC
Powheg+Herwig6
1.5
1
0.5
0
50
100
150
200
250
300
pTtt [GeV]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ZZ 1.14 ± 0.04 ± 0.05 35.9 fb-1
0.5
1
1.5
2
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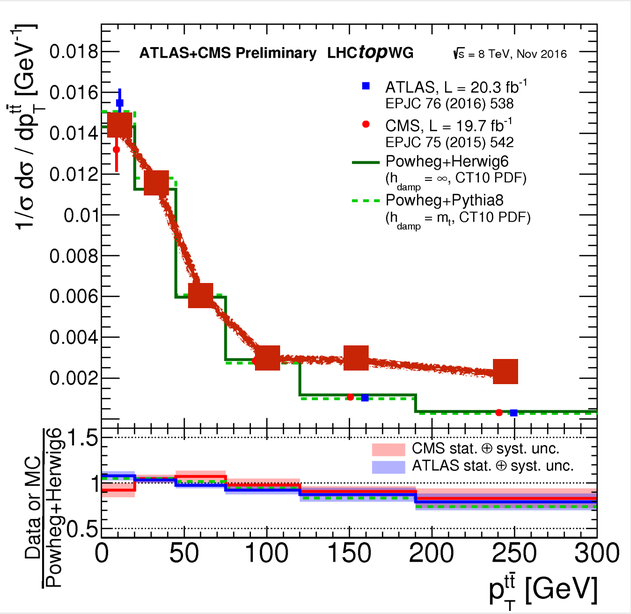
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Powheg+Pythia8
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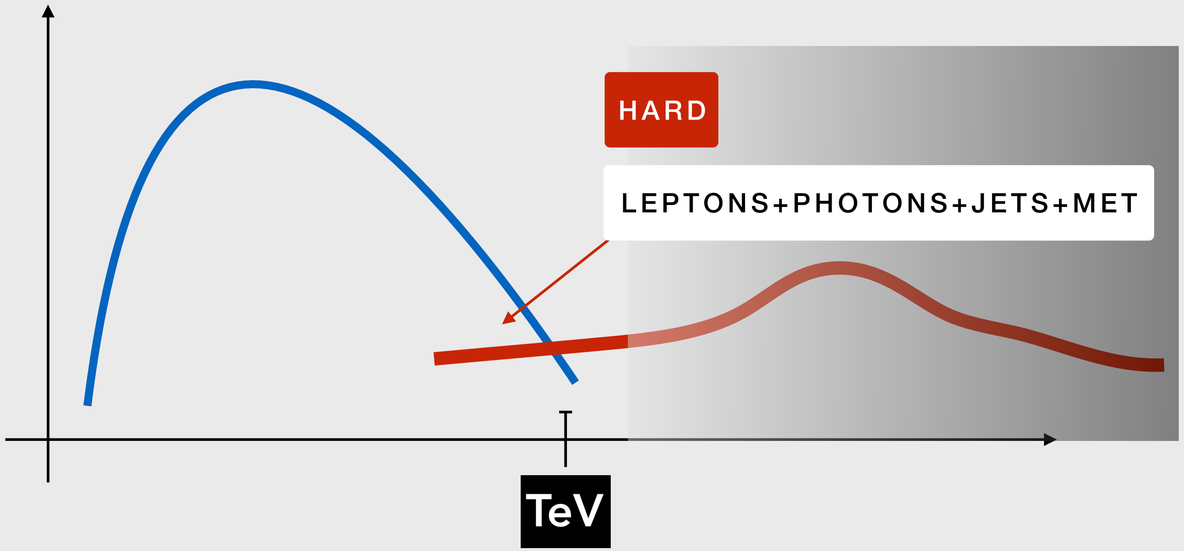
1/σ dσ / dpTtt [GeV-1]
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
CMS stat. ⊕ syst. unc.
ATLAS stat. ⊕ syst. unc.
Data or MC
Powheg+Herwig6
1.5
1
0.5
0
50
100
150
200
250
300
pTtt [GeV]

Ok, let’s see what we can do …

Precision Di-Bosons At The Hi-Lumi LHC

RF, Panico, Pomarol, Riva, Wulzer - in preparation

Effective Field Theory



$$L = L_{SM} + L_{new}$$

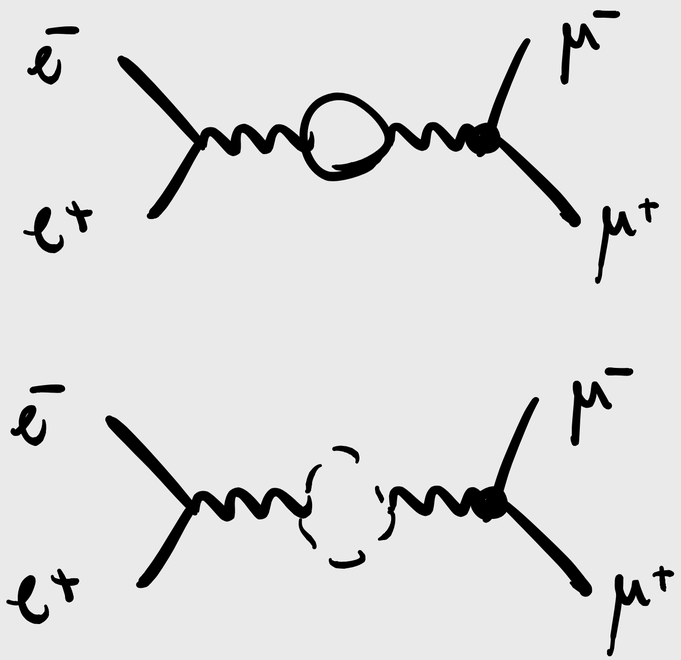
$$L_{new} = \Sigma_i \, O_i^{(d=6)}$$

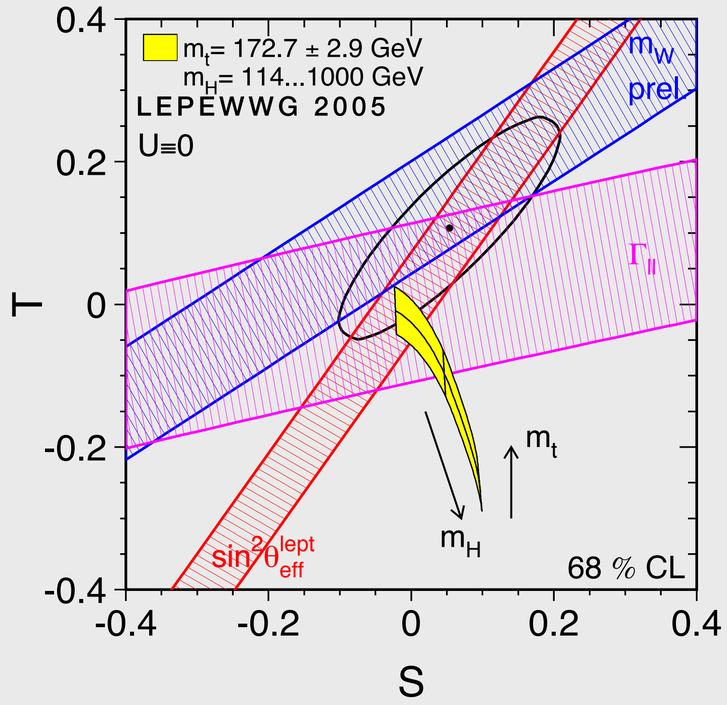
Large number of Operators dim-6

- What is worth being studied?
- What can be studied?

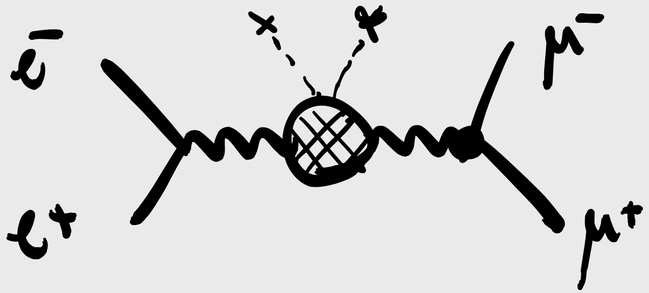
Operators related to SSB of EW symmetry

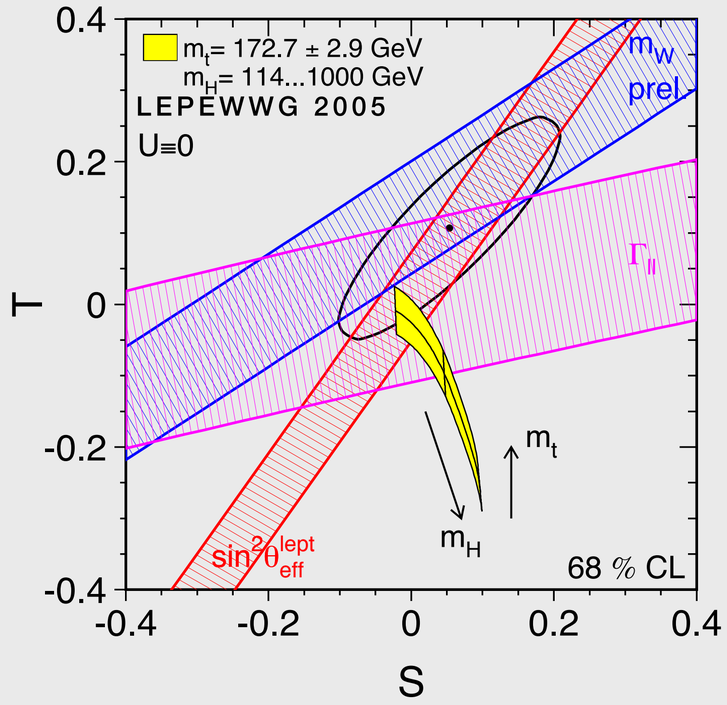
Indirect Effects





Indirect Effects

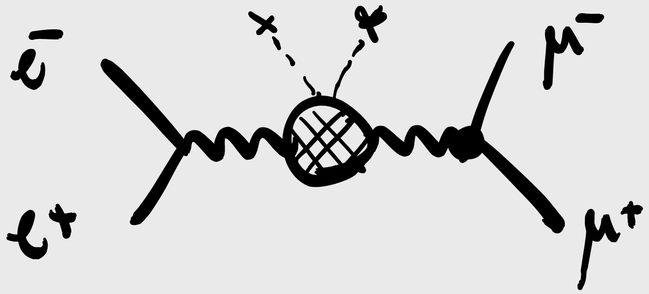




$$P_N = \begin{bmatrix} \frac{1}{q^2} - \frac{t^2\mathrm{W}+\mathrm{Y}}{m_Z^2} & \frac{t\left(\left(\mathrm{Y}+\hat{\mathrm{T}}\right)c^2+s^2\mathrm{W}-\hat{\mathrm{S}}\right)}{(c^2-s^2)\left(q^2-m_Z^2\right)} + \frac{t(\mathrm{Y}-\mathrm{W})}{m_Z^2} \\ \star & \frac{1+\hat{\mathrm{T}}-\mathrm{W}-t^2\mathrm{Y}}{q^2-m_Z^2} - \frac{t^2\mathrm{Y}+\mathrm{W}}{m_Z^2} \end{bmatrix}$$

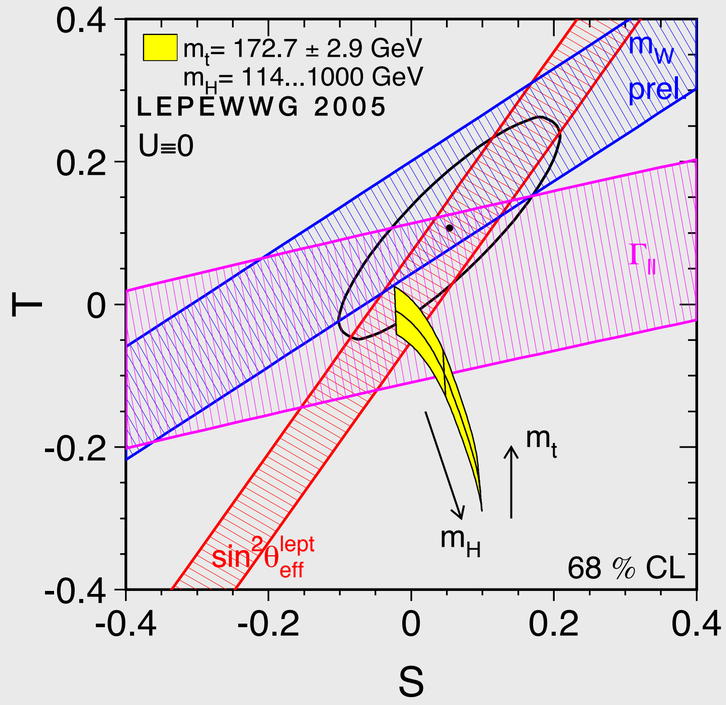
$$P_C = \frac{1+\left(\left(\hat{\mathrm{T}}-\mathrm{W}-t^2\mathrm{Y}\right)-2t^2\left(\hat{\mathrm{S}}-\mathrm{W}-\mathrm{Y}\right)\right)/(1-t^2)}{(q^2-m_W^2)} - \frac{\mathrm{W}}{m_W^2}$$

Indirect Effects



$$\frac{1}{\Lambda^2}\left(H^\dagger D H\right)^2$$

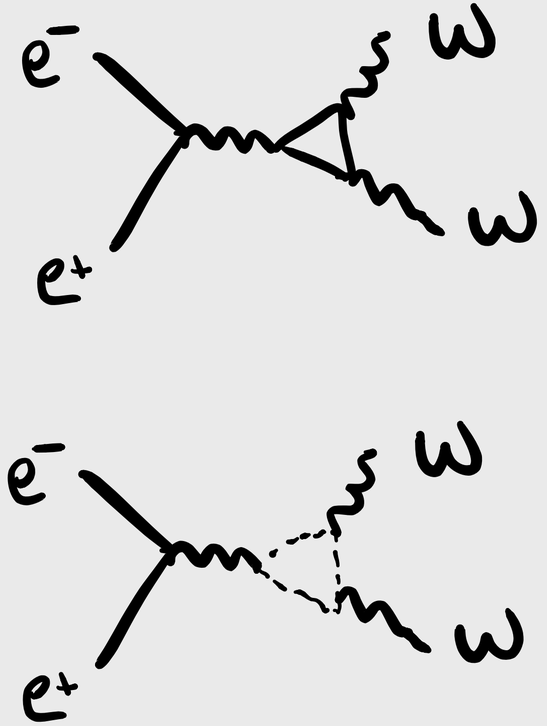
$$\frac{1}{\Lambda^2}\left(H^\dagger D H\right)\left(D W\right)$$

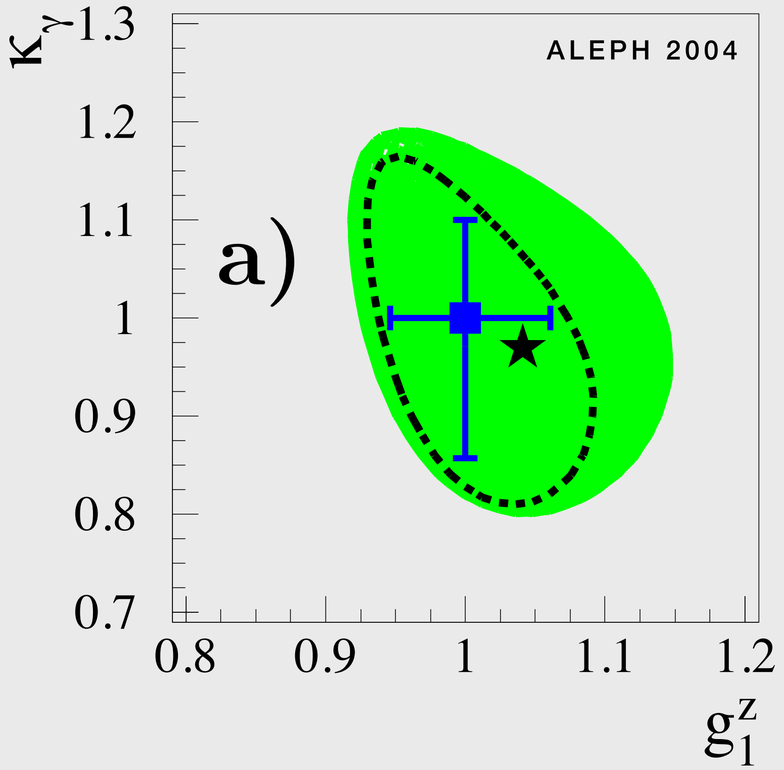


$$P_N = \begin{bmatrix} \frac{1}{q^2} - \frac{t^2\mathrm{W}+\mathrm{Y}}{m_Z^2} & \frac{t\left(\left(\mathrm{Y}+\hat{\mathrm{T}}\right)c^2+s^2\mathrm{W}-\hat{\mathrm{S}}\right)}{\left(c^2-s^2\right)\left(q^2-m_Z^2\right)} + \frac{t(\mathrm{Y}-\mathrm{W})}{m_Z^2} \\ \star & \frac{1+\hat{\mathrm{T}}-\mathrm{W}-t^2\mathrm{Y}}{q^2-m_Z^2} - \frac{t^2\mathrm{Y}+\mathrm{W}}{m_Z^2} \end{bmatrix}$$

$$P_C = \frac{1+\left(\left(\hat{\mathrm{T}}-\mathrm{W}-t^2\mathrm{Y}\right)-2t^2\left(\hat{\mathrm{S}}-\mathrm{W}-\mathrm{Y}\right)\right)/\left(1-t^2\right)}{\left(q^2-m_W^2\right)} - \frac{\mathrm{W}}{m_W^2}$$

Indirect Searches

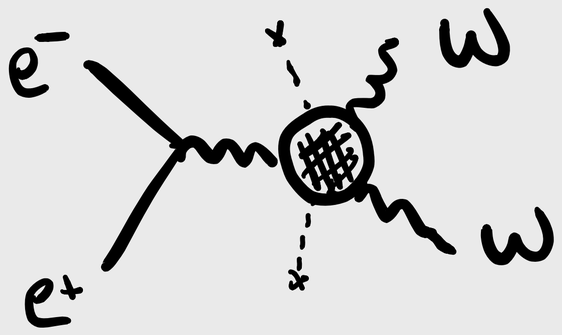


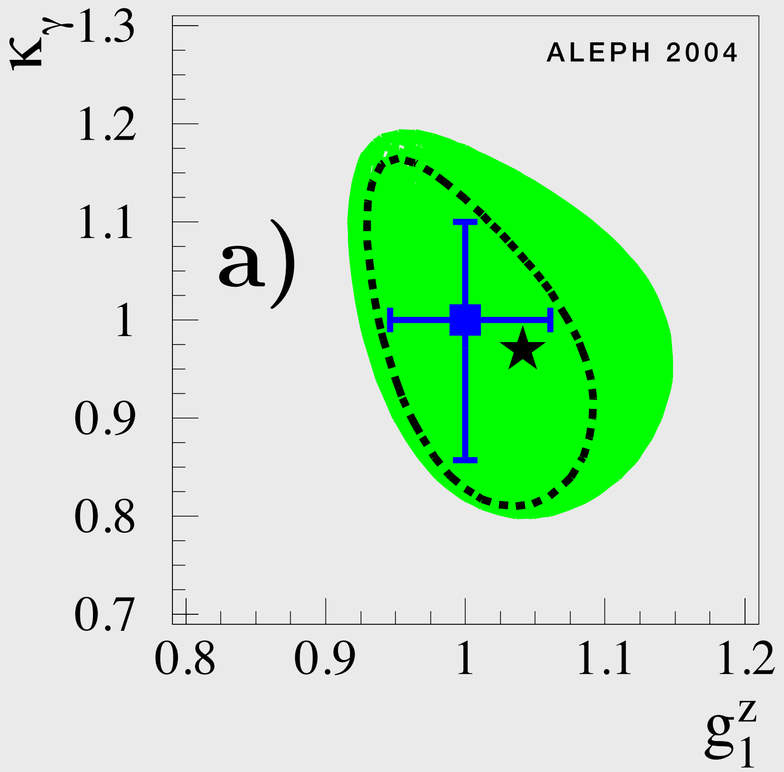


$$igc_{\theta_W}\boldsymbol{\delta g_1^Z}\left[(Z^\mu(W^{+\nu}W^-_{\mu\nu}-\text{h.c.})+Z^{\mu\nu}W^+_\mu W^-_\nu\right]$$

$$ie\,\boldsymbol{\delta\kappa_\gamma}\,(A_{\mu\nu}-t_{\theta_W}Z_{\mu\nu})W^{+\mu}W^{-\nu}\,,$$

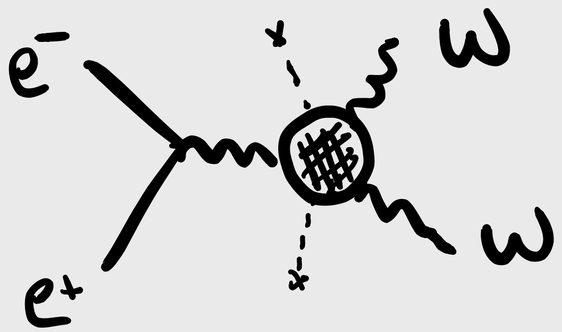
Indirect Searches



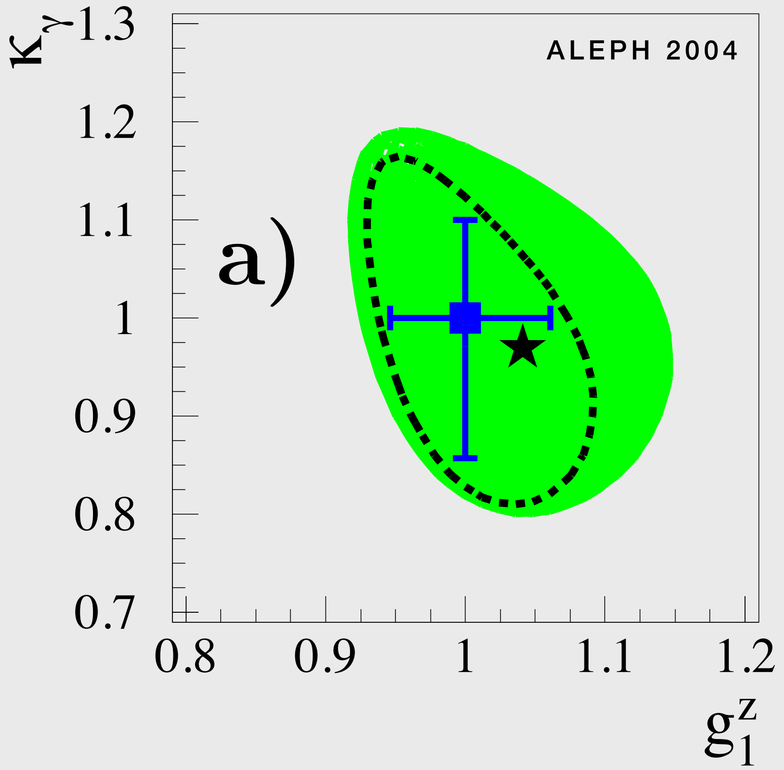


$$igc_{\theta_W}\boldsymbol{\delta g_1^Z}\left[(Z^\mu(W^{+\nu}W^-_{\mu\nu}-\text{h.c.})+Z^{\mu\nu}W^+_\mu W^-_\nu\right]$$
$$ie\,\boldsymbol{\delta\kappa_\gamma}\,(A_{\mu\nu}-t_{\theta_W}Z_{\mu\nu})W^{+\mu}W^{-\nu}\,,$$

Indirect Searches



$$\frac{1}{\Lambda^2}(D H)(D H) W$$



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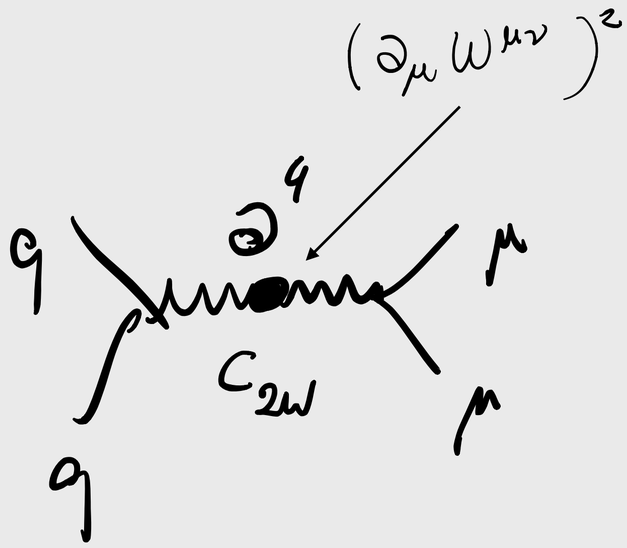
Can LHC compete with LEP?

ENERGY HELPS ACCURACY

- Some effects are overall changes in the scattering amplitudes (*e.g.* S,T)
- Other effects are enhanced at high-energy (LHC is high energy!)

DRELL-YAN

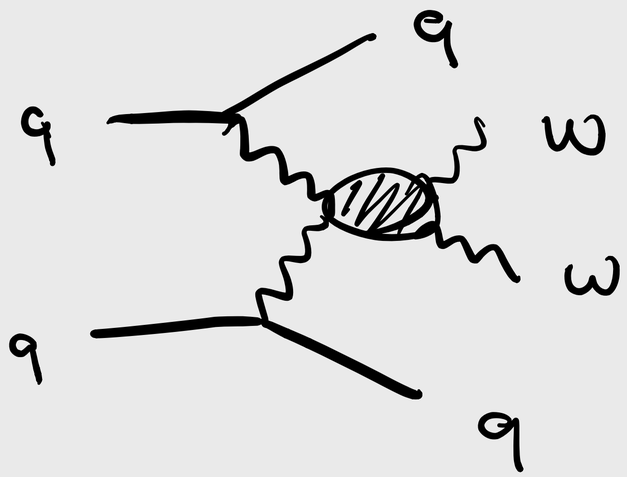


Can LHC compete with LEP?

ENERGY HELPS ACCURACY

- Are there EWSB effects enhanced at high-energy?

"WW" SCATTERING



Can LHC compete with LEP?

ENERGY

HELPS ACCURACY

“WW” SCATTERING

- Are there EWSB effects enhanced at high-energy?

Can LHC compete with LEP?

ENERGY HELPS ACCURACY

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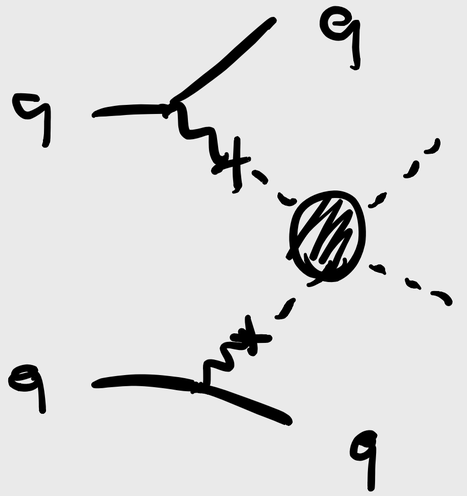

Can LHC compete with LEP?

ENERGY HELPS ACCURACY

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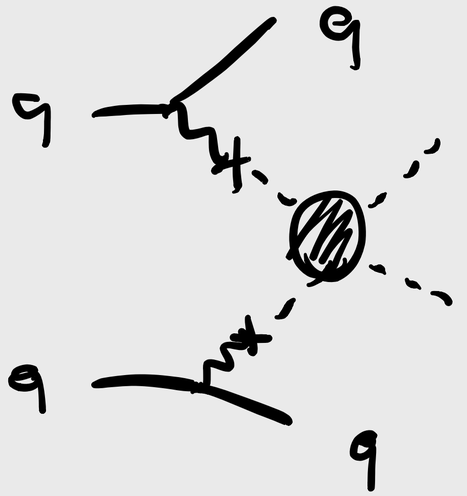


weakly coupled EWSB: low S/B

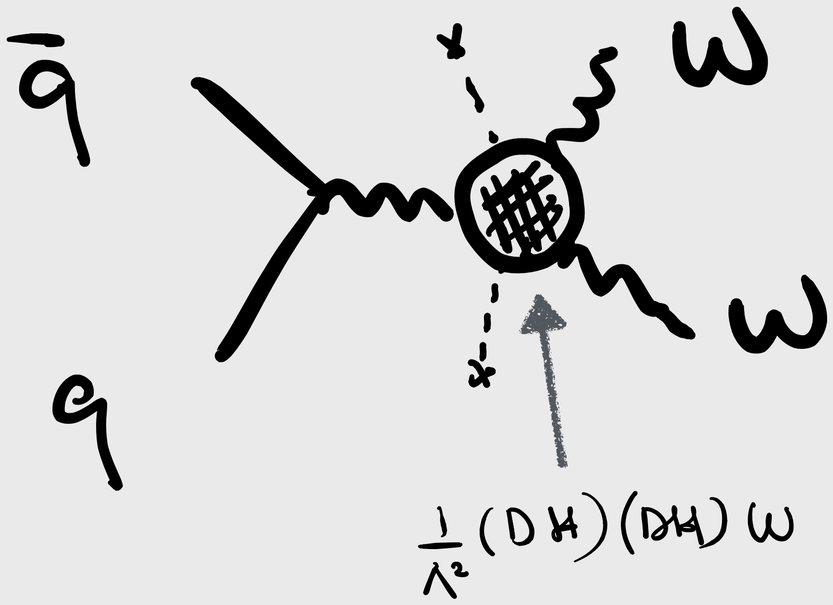
Can LHC compete with LEP?

ENERGY

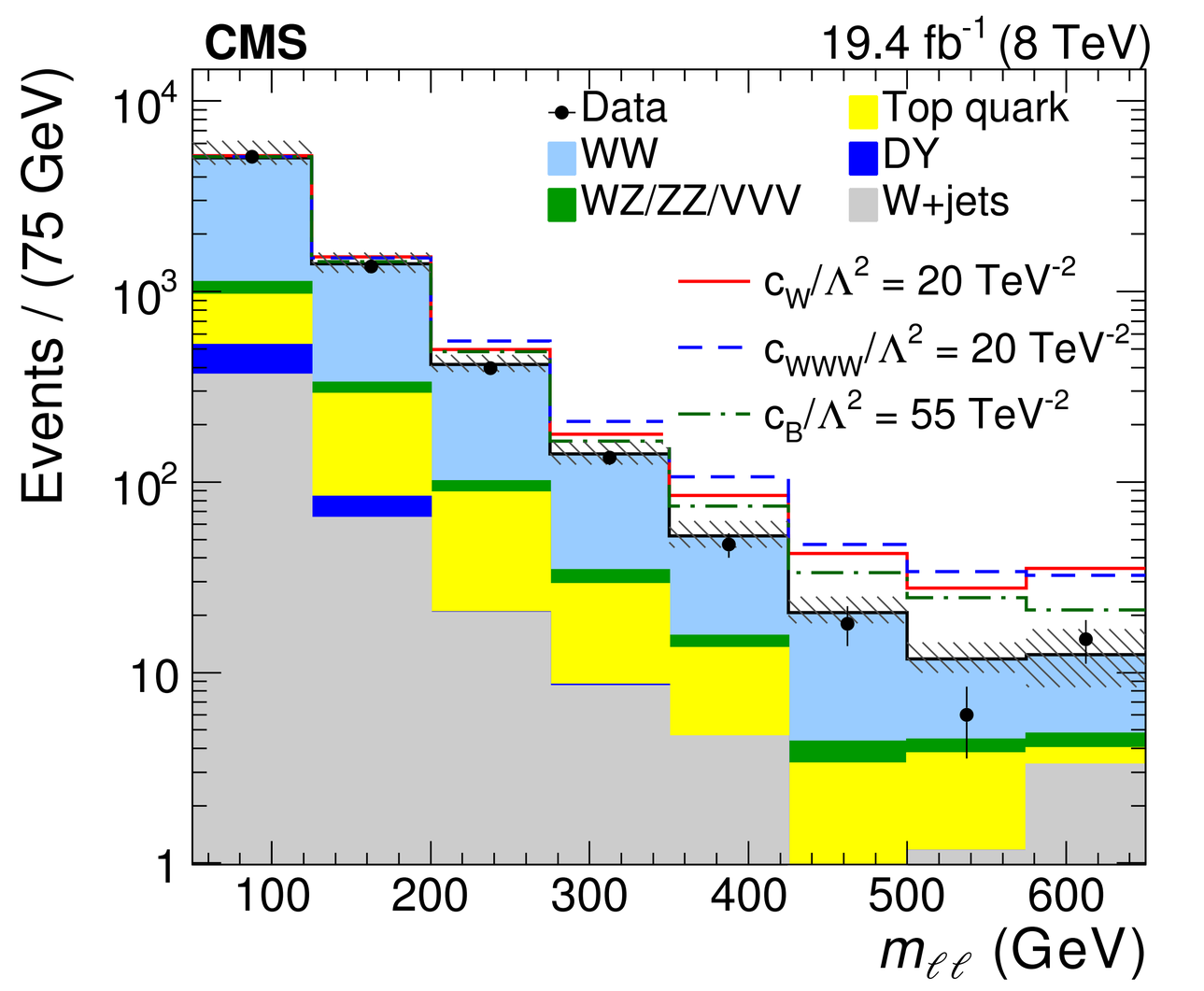
HELPS ACCURACY

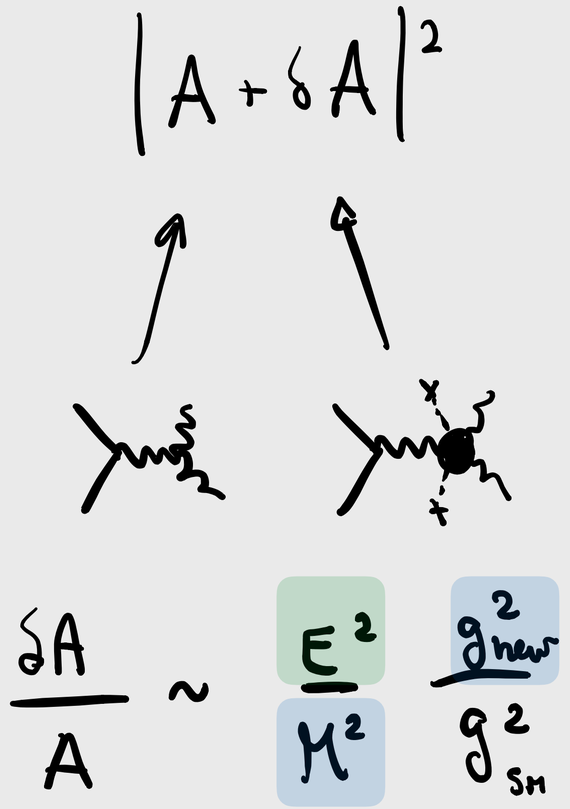
- Are there **observable** EWSB effects enhanced at high-energy from **weakly coupled SSB**?

DIBOSON PRODUCTION



Bounds on …

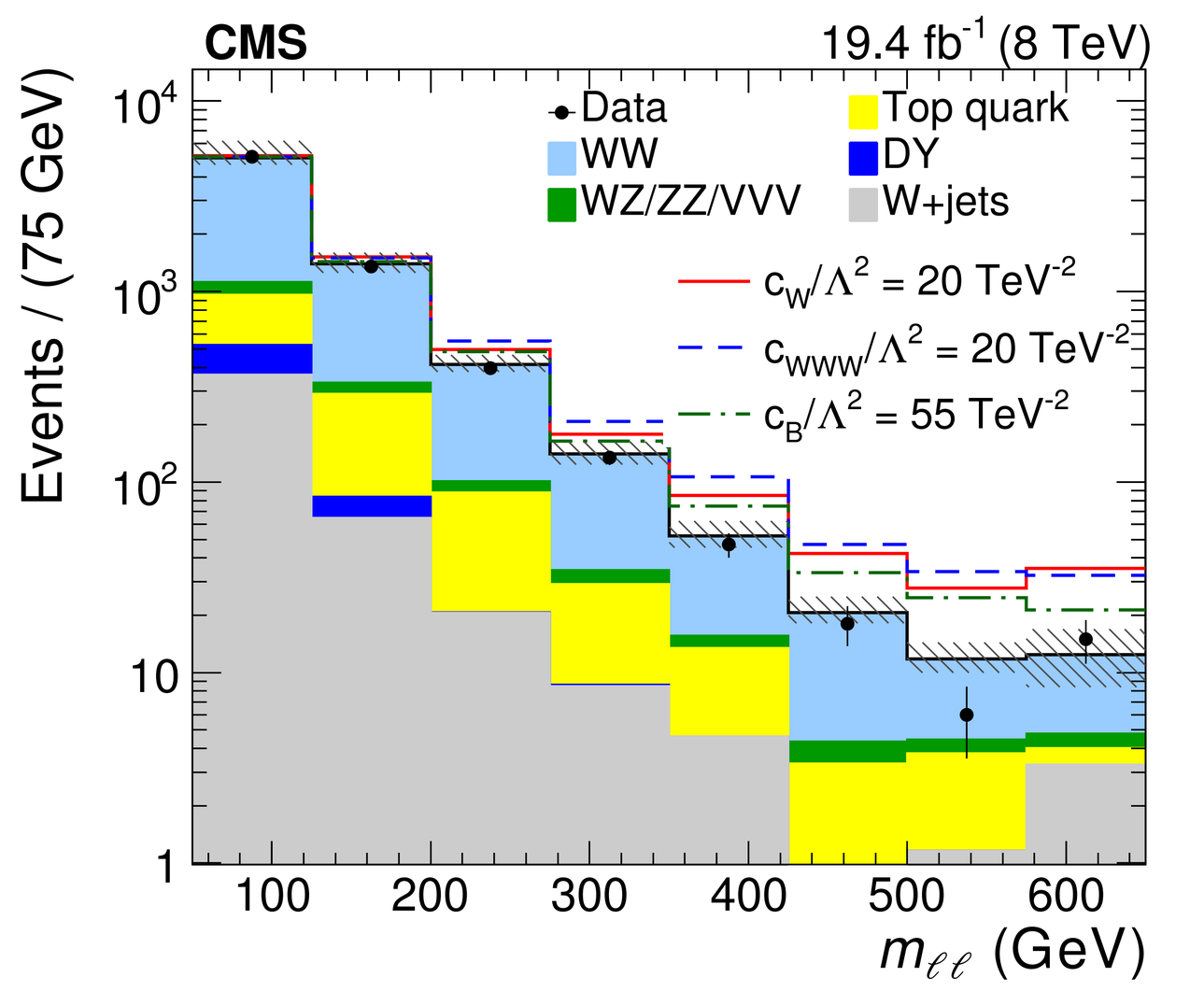


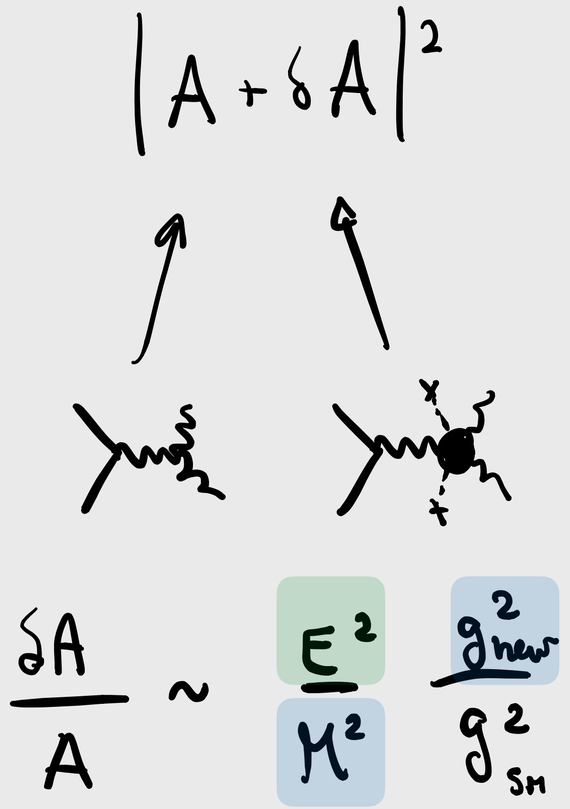


$$A = |A_{SM} + \varepsilon A_{new}|^2$$

$$A \simeq A_{SM} + 2\varepsilon A_{new}$$

Bounds on …

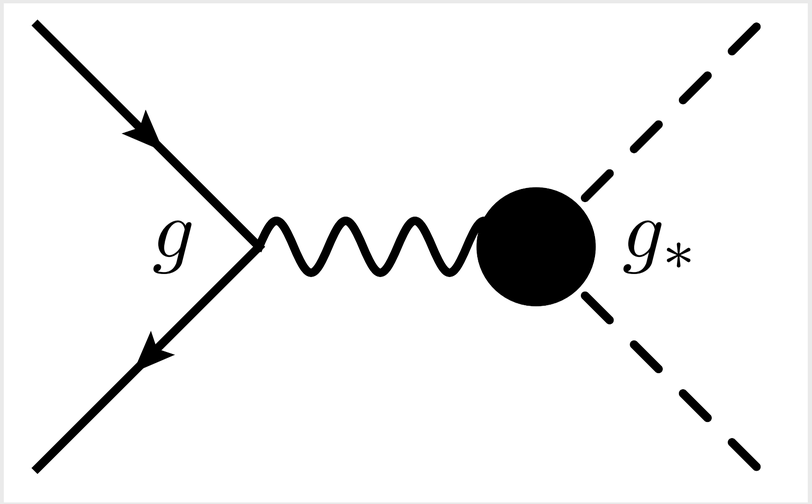




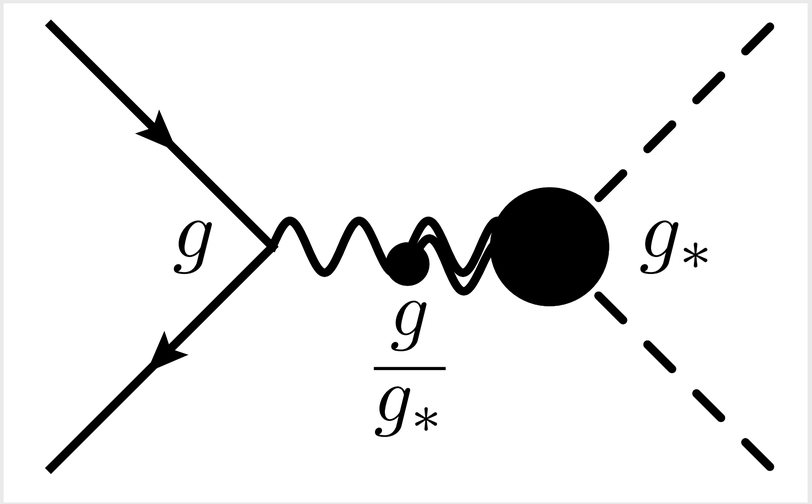
$$A = |A_{SM} + \varepsilon A_{new}|^2$$

$$A \simeq A_{SM} + 2\varepsilon A_{new}$$

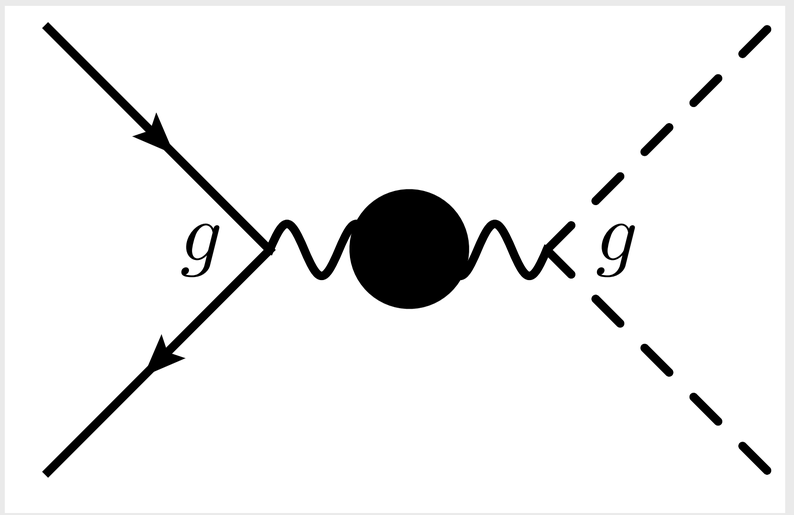
Strong, Weak, and Loop



COMPOSITE HIGGS



SUSY



Interference

- Interference must be the dominant BSM effect
- Higher energy to gain sensitivity $\frac{\delta A}{A} \sim \frac{E^2}{M^2} \frac{g^2_{new}}{g^2_{SM}}$

10% at 1 TeV ~ 0.1% at 100 GeV

High energy "primary" effects

ENCAPSULATE **ANY** BSM EFFECTS IN DIBOSON IN JUST FEW OBSERVABLES

ANOMALOUS COUPLINGS

Amplitude	High-energy primaries	Deviations from SM couplings
$\bar{u}_L d_L \to W_L Z_L, W_L h$	$\sqrt{2} a_q^{(3)}$	$\sqrt{2}\frac{g^2\Lambda^2}{4m_W^2}\left[c_{\theta_W}(\boldsymbol{\delta g^Z_{uL}} - \boldsymbol{\delta g^Z_{dL}})/g - c^2_{\theta_W}\boldsymbol{\delta g^Z_1}\right]$
$\bar{u}_L u_L \to W_L W_L$ $\bar{d}_L d_L \to Z_L h$	$a_q^{(1)} + a_q^{(3)}$	$-\frac{g^2\Lambda^2}{2m_W^2}\left[Y_L t^2_{\theta_W}\boldsymbol{\delta\kappa_\gamma} + T_Z^{u_L}\boldsymbol{\delta g^Z_1} + c_{\theta_W}\boldsymbol{\delta g^Z_{dL}}/g\right]$
$\bar{d}_L d_L \to W_L W_L$ $\bar{u}_L u_L \to Z_L h$	$a_q^{(1)} - a_q^{(3)}$	$-\frac{g^2\Lambda^2}{2m_W^2}\left[Y_L t^2_{\theta_W}\boldsymbol{\delta\kappa_\gamma} + T_Z^{d_L}\boldsymbol{\delta g^Z_1} + c_{\theta_W}\boldsymbol{\delta g^Z_{uL}}/g\right]$
$\bar{f}_R f_R \to W_L W_L, Z_L h$	a_f	$-\frac{g^2\Lambda^2}{2m_W^2}\left[Y_{f_R} t^2_{\theta_W}\boldsymbol{\delta\kappa_\gamma} + T_Z^{f_R}\boldsymbol{\delta g^Z_1} + c_{\theta_W}\boldsymbol{\delta g^Z_{fR}}/g\right]$

"WARSAW BASIS"

$$\mathcal{O}_L^{(3)} = (\bar{Q}_L\sigma^a\gamma^\mu Q_L)(iH^\dagger\sigma^a\overleftrightarrow{D}_\mu H)$$
$$\mathcal{O}_L = (\bar{Q}_L\gamma^\mu Q_L)(iH^\dagger\overleftrightarrow{D}_\mu H)$$
$$\mathcal{O}_R^u = (\bar{u}_R\gamma^\mu u_R)(iH^\dagger\overleftrightarrow{D}_\mu H)$$
$$\mathcal{O}_R^d = (\bar{d}_R\gamma^\mu d_R)(iH^\dagger\overleftrightarrow{D}_\mu H)$$

"SILH" BASIS

$$\mathcal{O}_W = \frac{ig}{2}\left(H^\dagger\sigma^a\overleftrightarrow{D^\mu}H\right)D^\nu W^a_{\mu\nu}$$
$$\mathcal{O}_B = \frac{ig'}{2}\left(H^\dagger\overleftrightarrow{D^\mu}H\right)\partial^\nu B_{\mu\nu}$$
$$\mathcal{O}_{HW} = ig(D^\mu H)^\dagger\sigma^a(D^\nu H)W^a_{\mu\nu}$$
$$\mathcal{O}_{HB} = ig'(D^\mu H)^\dagger(D^\nu H)B_{\mu\nu}$$
$$\mathcal{O}_{2W} = -\frac{1}{2}(D^\mu W^a_{\mu\nu})^2$$
$$\mathcal{O}_{2B} = -\frac{1}{2}(\partial^\mu B_{\mu\nu})^2$$

- 4 high energy primary effects
- physics interpretation is transparent (BSM origin)
- 1-to-1 with Warsaw basis operators

for instance:

$$L_{new} \sim J_Y J_Y + J_W J_W \Rightarrow a_u = -2a_d = 4a_q^{(1)}$$

"UNIVERSAL" THEORY

$pp \to \phi\phi$

GOLDSTONE BOSONS PRODUCTION AT THE LHC

$\phi \simeq V_L \subset V$ because $V=\{V_L, V_\pm\}$

$pp \to ZZ$ has no E^2 enhancement

$pp \to VH$ has large QCD background (Z+jets)

$pp \to WW$ has large QCD background (tt,W+jets, mET=ν+ν)

$pp \to ZW \to 3\ell$ has no QCD background, mET≃ν, $d\sigma(W_\pm Z_\pm) \simeq 0$ at $\theta^* \simeq 90$deg

$pp \to \phi\phi$

GOLDSTONE BOSONS PRODUCTION AT THE LHC

		$p_{T,V}$ range (GeV)			
Channel		[200, 400]	[400, 600]	[600, 1000]	[1000, 2000]
$W^\pm h$	$W_L^\pm h$	$23300 + 42500\, a_q^{(3)}$	$1950 + 9750\, a_q^{(3)}$	$420 + 4680\, a_q^{(3)}$	
	$W_L h$ substr. [44]	$2230 + 4070\, a_q^{(3)}$	$368 + 1840\, a_q^{(3)}$	$108 + 1200\, a_q^{(3)}$	
	background [44]	11400	1720	700	
Zh	$Z_L h$	$3760 + 5330\, a_q^{(3)}$	$294 + 1350\, a_q^{(3)}$	$58 + 600\, a_q^{(3)}$	
	$Z_L h$ substr. [44]	$600 + 850\, a_q^{(3)}$	$84 + 390\, a_q^{(3)}$	$17 + 178\, a_q^{(3)}$	
W^+W^-	$W_L W_L$	$5080 + 7450\, a_q^{(3)}$	$380 + 1730\, a_q^{(3)}$	$74 + 780\, a_q^{(3)}$	$5.8 + 160\, a_q^{(3)}$
	other helicities	89500	5500	990	69
$W^\pm Z$	$W_L Z_L$	$2970 + 5050\, a_q^{(3)}$	$226 + 1200\, a_q^{(3)}$	$46 + 540\, a_q^{(3)}$	$3.7 + 123\, a_q^{(3)}$
	other helicities	10800	600	100	6.0

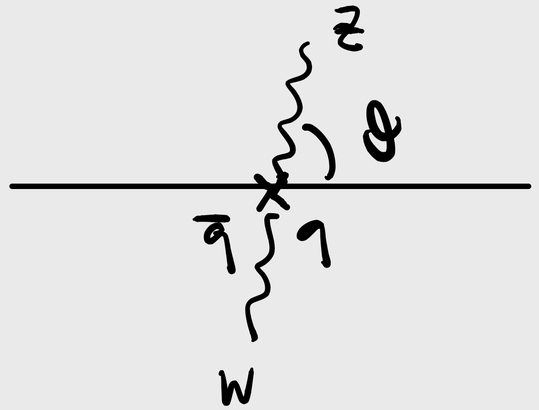
Channel	Bound without bkg.	Bound with bkg.
Wh	$[-0.0096, 0.0096]$	$[-0.036, 0.031]$
Zh	$[-0.030, 0.028]$	–
WW	$[-0.012, 0.011]$	$[-0.044, 0.037]$
WZ	$[-0.013, 0.012]$	$[-0.023, 0.021]$

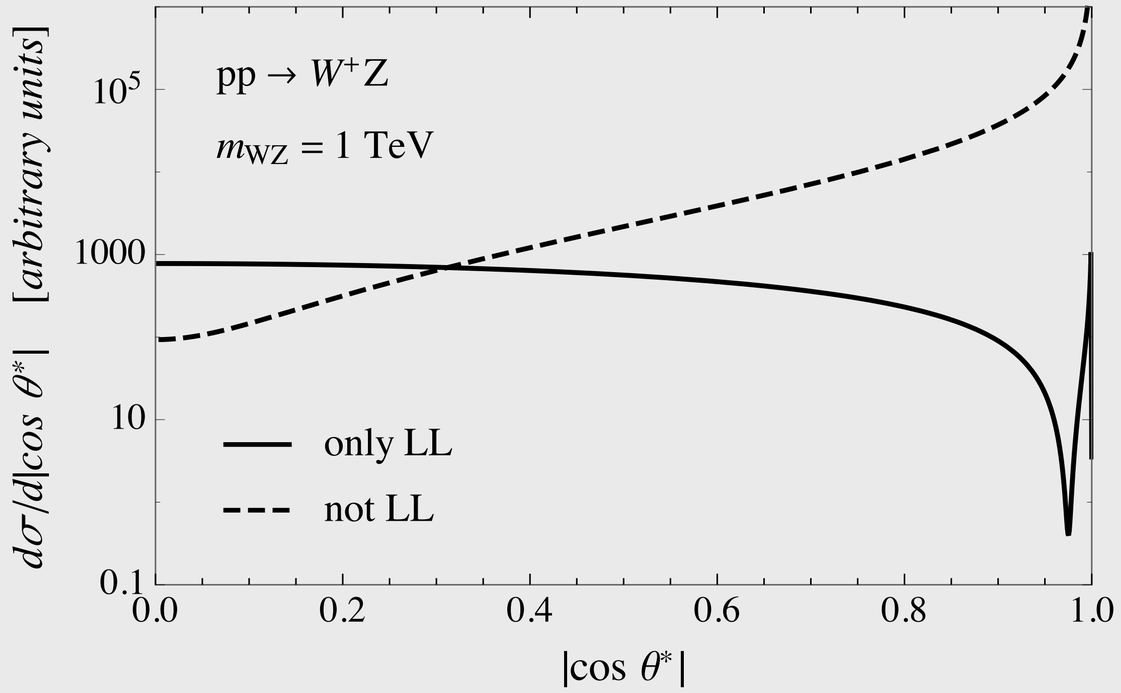
hep-ph/9403248

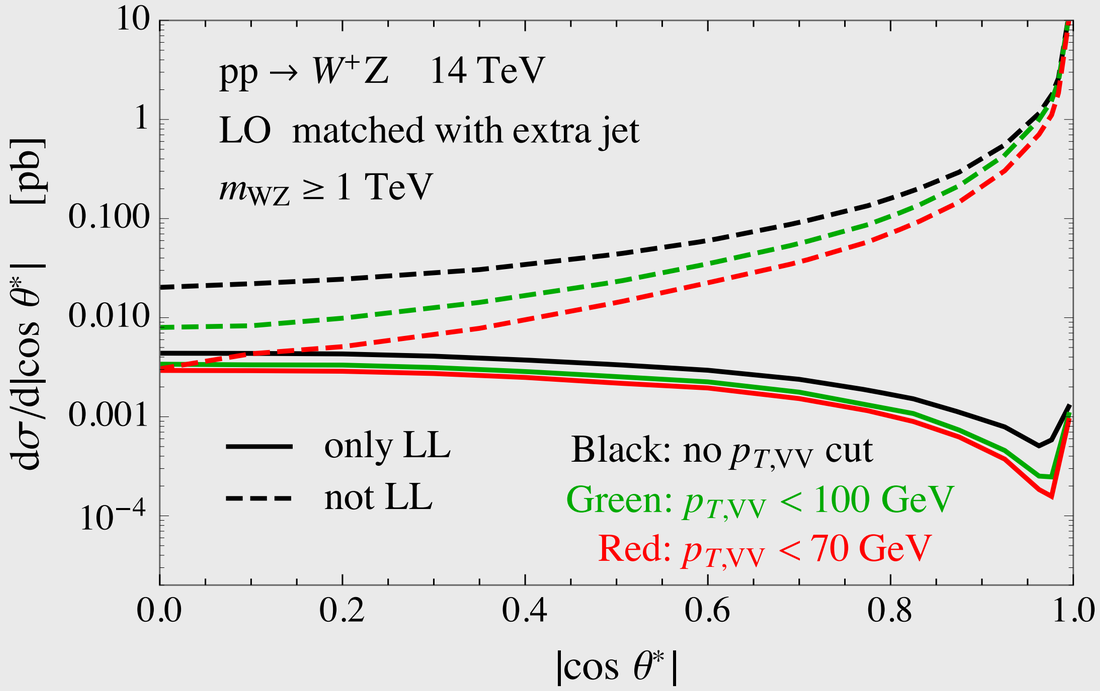
1510.08451

$pp \to ZW \to 3\ell$

GOLDSTONE BOSONS PRODUCTION AT THE LHC







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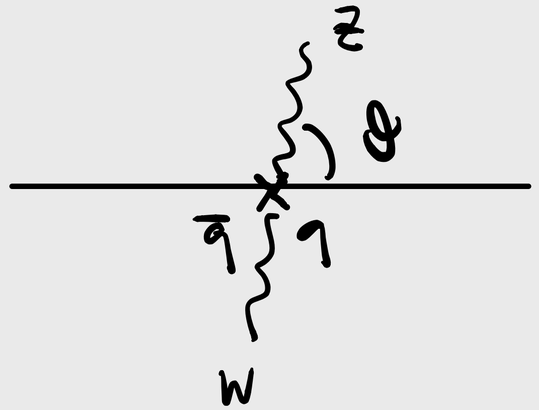
GOLDSTONE BOSONS PRODUCTION AT THE LHC



$$A(u\bar{d} \to W^+_{(\pm)} Z_{(\mp)}) \propto \cos\theta_{WZ} - \frac{1}{3}\tan\theta_W$$

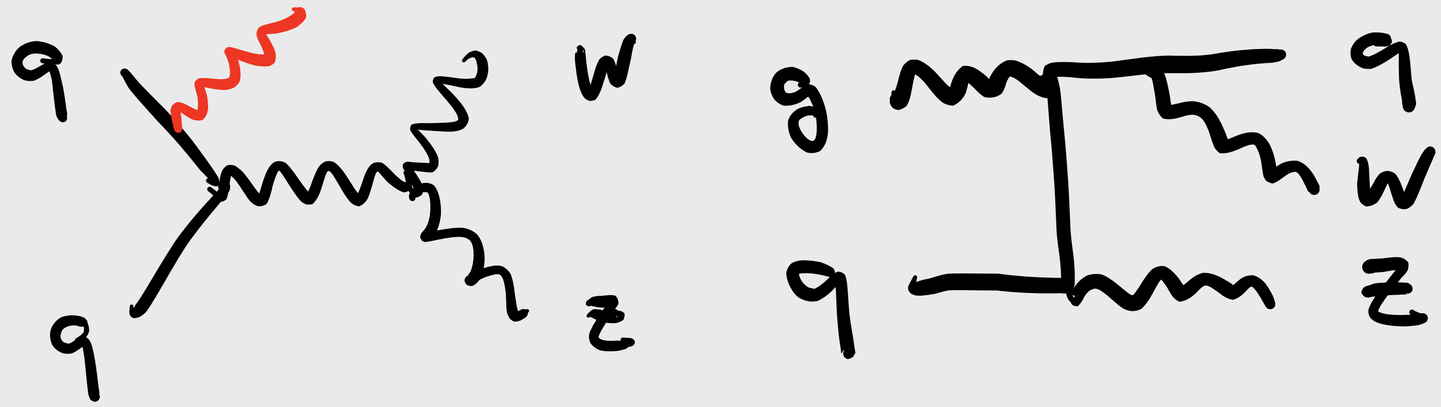
$$A(u\bar{d} \to W^+_{(0)} Z_{(0)}) \propto \sin\theta_{WZ}$$

$q\bar{q} \to ZW$ is $2\times2 \to 3\times3$ under SU(2)

$q\bar{q} \to \phi\phi$ is $2\times2 \to 2\times2$ under SU(2)

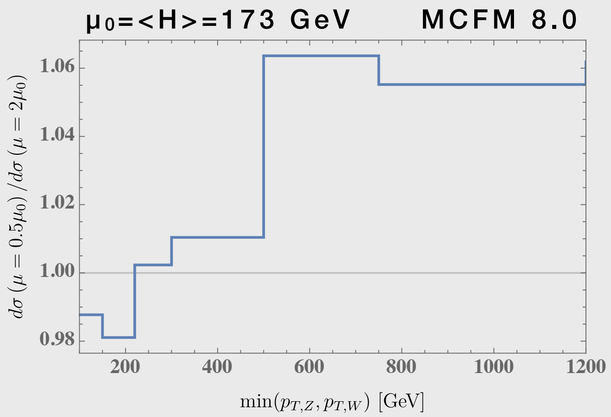
$$p_{T,\ell} > 30\,\text{GeV} \qquad |\eta_\ell| < 2.4$$

$$|\cos\Theta| < 0.5, \qquad \frac{p_{T,VV}}{p_{T,V}} < 0.5$$



$pp \to ZW \to 3\ell$

GOLDSTONE BOSONS PRODUCTION AT THE LHC



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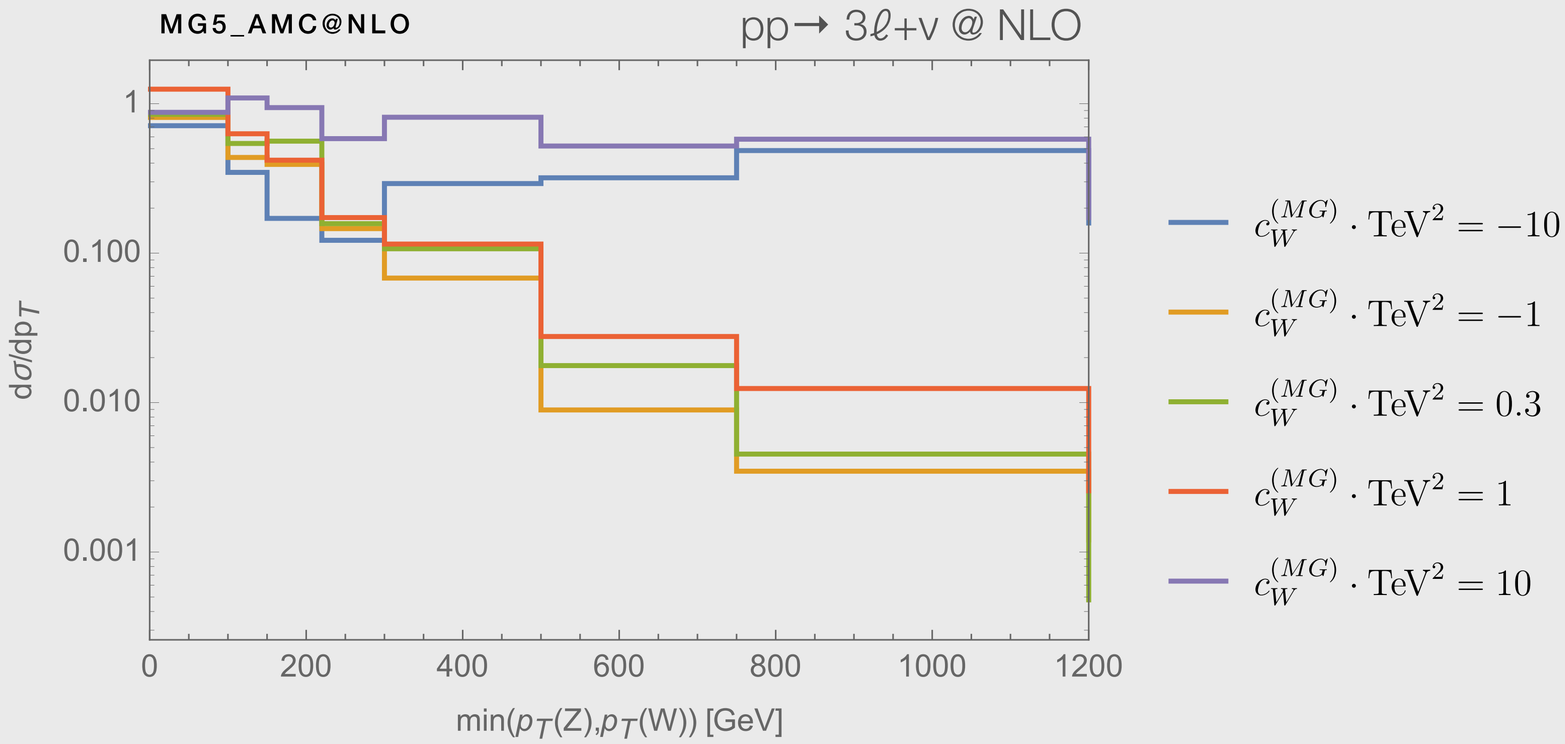


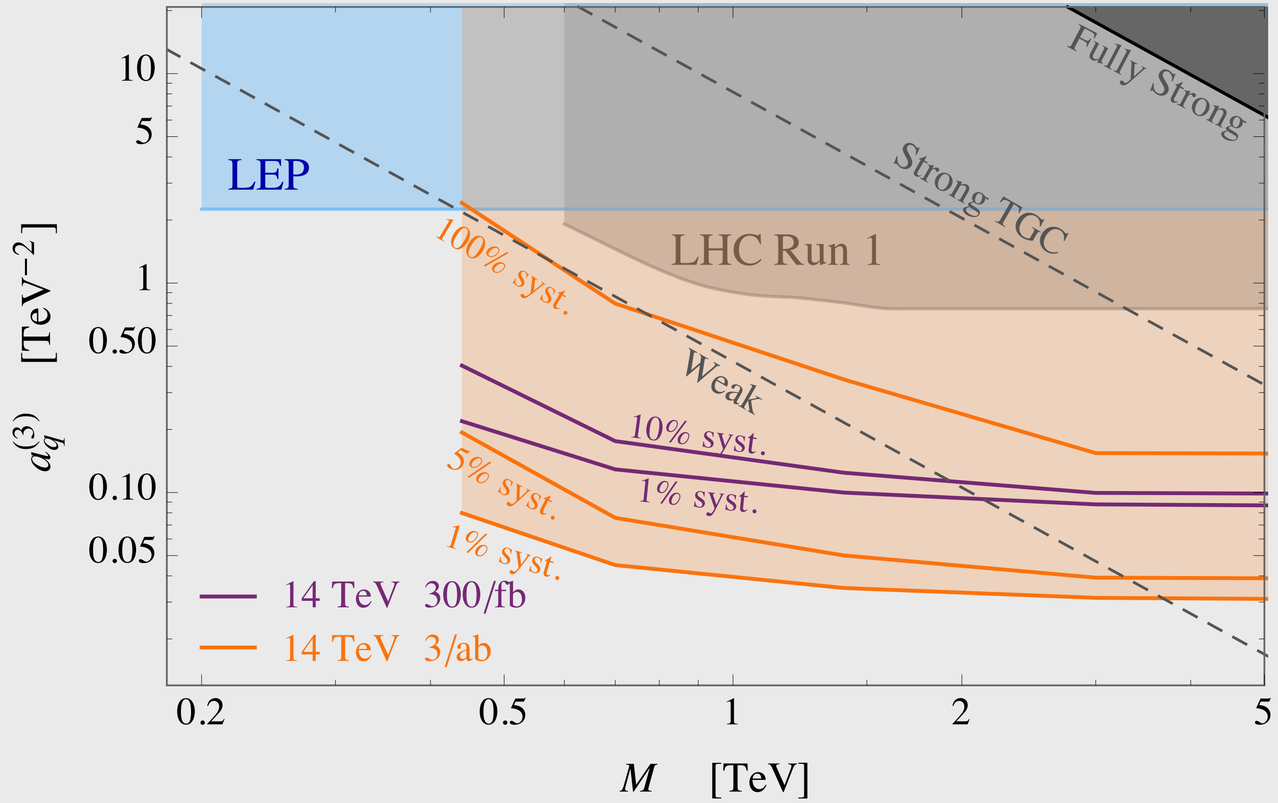
$pp \to ZW \to 3\ell$

Low systematics is a key!

GOLDSTONE BOSONS PRODUCTION AT THE LHC

$p_{T,V}$ range	Expected Events
[100-150] GeV	$3100 + 1040\ a_q^{(3)} + 260\ a_q^{(3)\,2}$
[150-220] GeV	$2620 + 1030\ a_q^{(3)} + 140\ a_q^{(3)\,2}$
[220-300] GeV	$937 + 600\ a_q^{(3)} + 230\ a_q^{(3)\,2}$
[300-500] GeV	$544 + 700\ a_q^{(3)} + 560\ a_q^{(3)\,2}$
[500-750] GeV	$86.5 + 260\ a_q^{(3)} + 490\ a_q^{(3)\,2}$
[750-1200] GeV	$16.1 + 120\ a_q^{(3)} + 640\ a_q^{(3)\,2}$

$$\text{LHC, } 300\,\text{fb}^{-1}: \quad a_q^{(3)} \in [-1.4, 0.9]\,10^{-1}\ \text{TeV}^{-2} \quad \delta_{\text{syst}} = 5\%$$
$$\text{HL-LHC, } 3\,\text{ab}^{-1}: \quad a_q^{(3)} \in [-4.9, 3.9]\,10^{-2}\ \text{TeV}^{-2} \quad \delta_{\text{syst}} = 5\%$$
$$\text{HE-LHC, } 10\,\text{ab}^{-1}: \quad a_q^{(3)} \in [-1.6, 1.3]\,10^{-2}\ \text{TeV}^{-2} \quad \delta_{\text{syst}} = 5\%$$
$$\text{FCC-hh, } 20\,\text{ab}^{-1}: \quad a_q^{(3)} \in [-7.3, 5.7]\,10^{-3}\ \text{TeV}^{-2} \quad \delta_{\text{syst}} = 5\%$$



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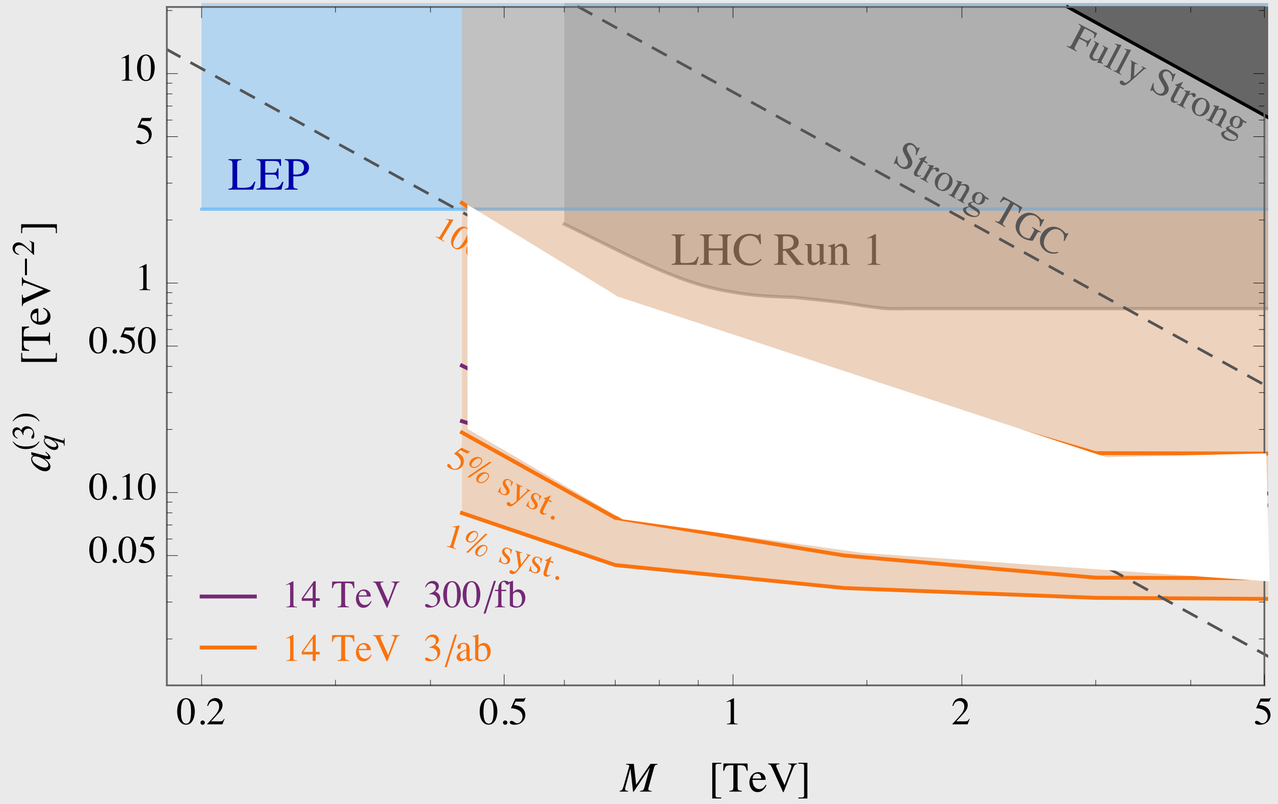

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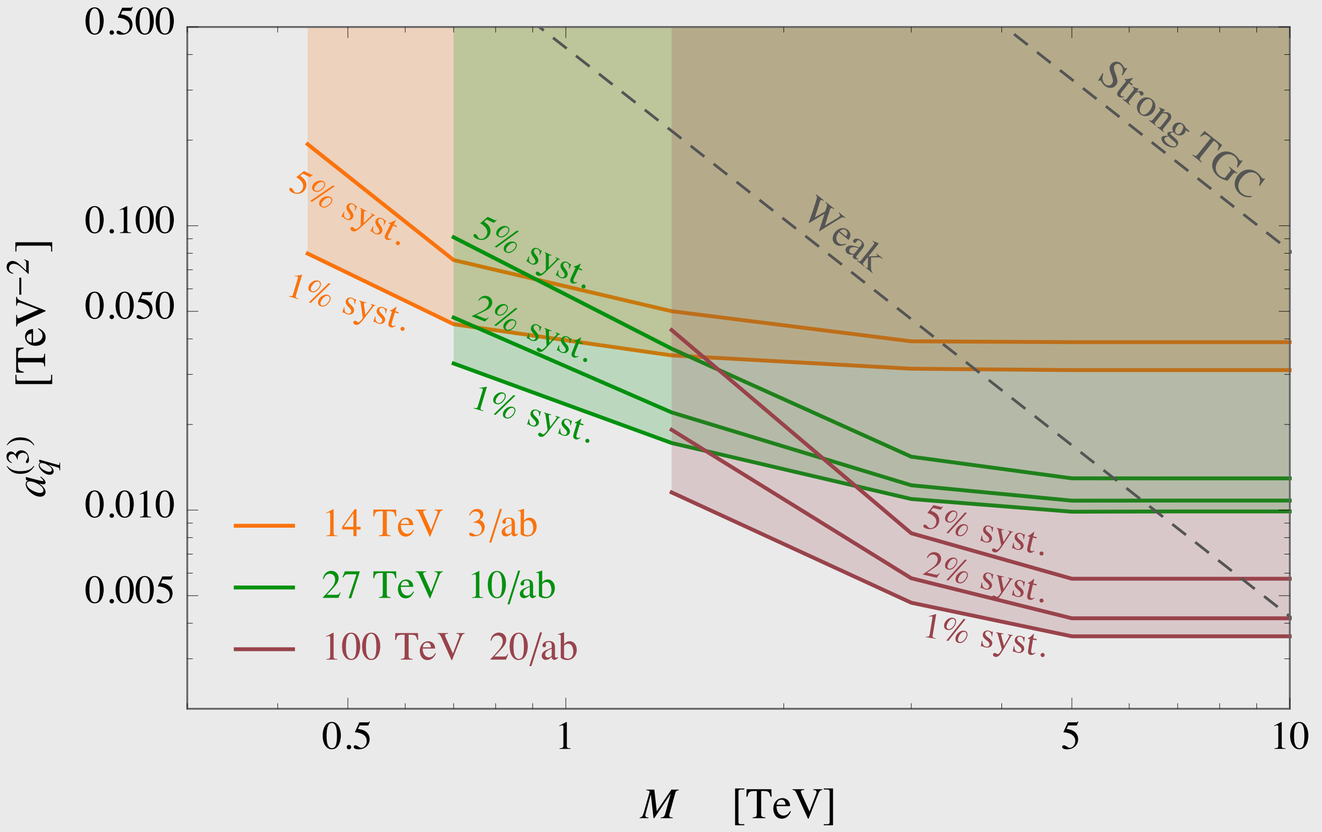
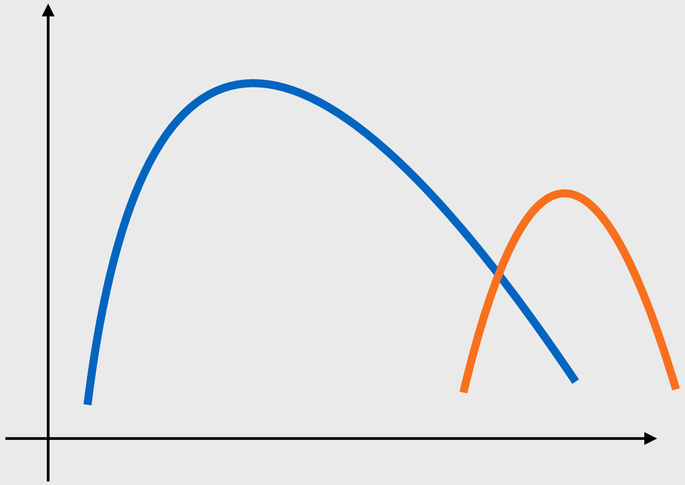
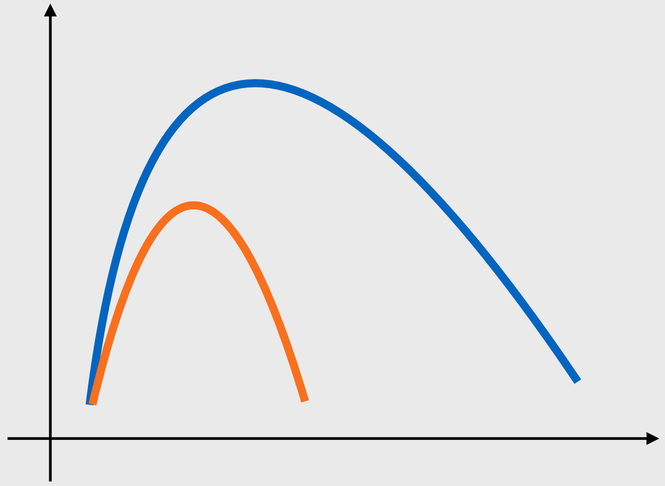
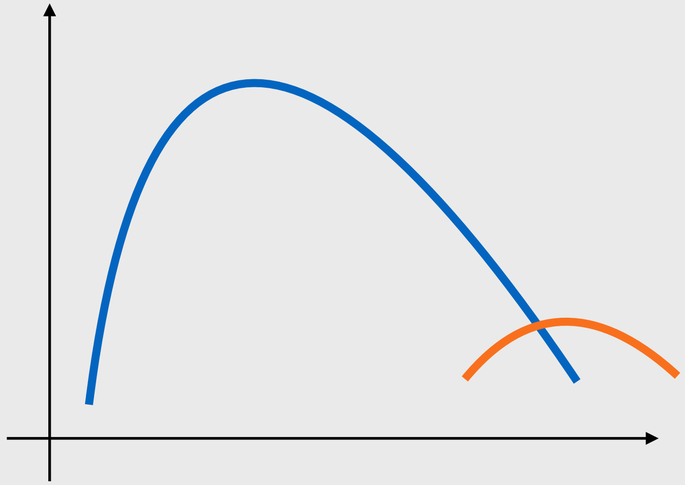








RUN1

RUN2,3, HI-LUMI

Time

S/B

Conclusions

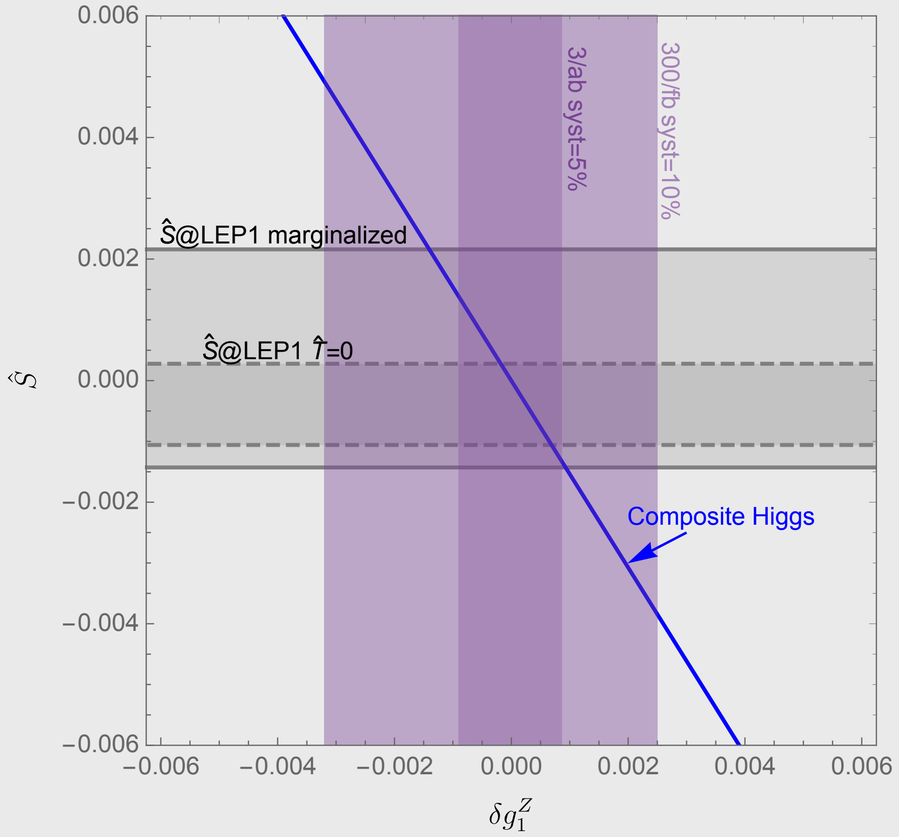
- LHC can still do interesting new physics searches (not just new particles!)
- Interesting scenarios probed through "precision"
- E^2-enhanced processes are a target for LHC to extend knowledge of EWSB **10% at 1 TeV ~ 0.1% at 100 GeV**
- Theory and Experiment systematics target at 10% in TeV p_T region

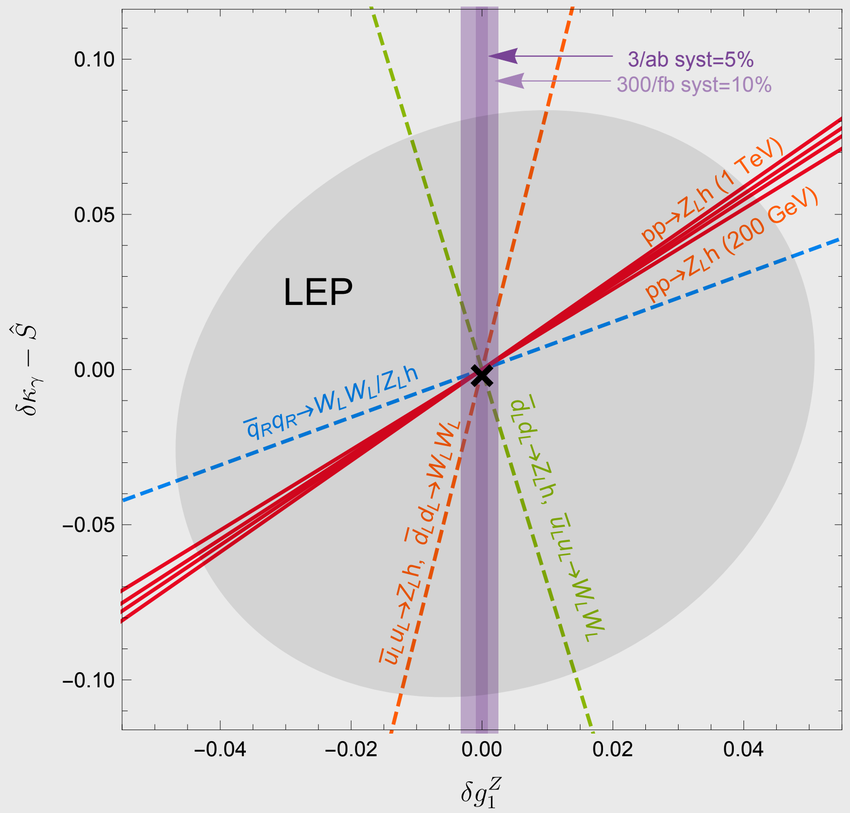
Conclusions

- Constraints on weakly coupled EWSB models from the dim-6 SM Lagrangian at LHC from pp → WZ, possibly pp → ZH, WW, WH
- General parametrization of BSM effects for pp→ VV and pp→VH

Conclusions

- Prospects for High-Lumi LHC on weakly coupled EWSB dim-6 effects





Thank You!

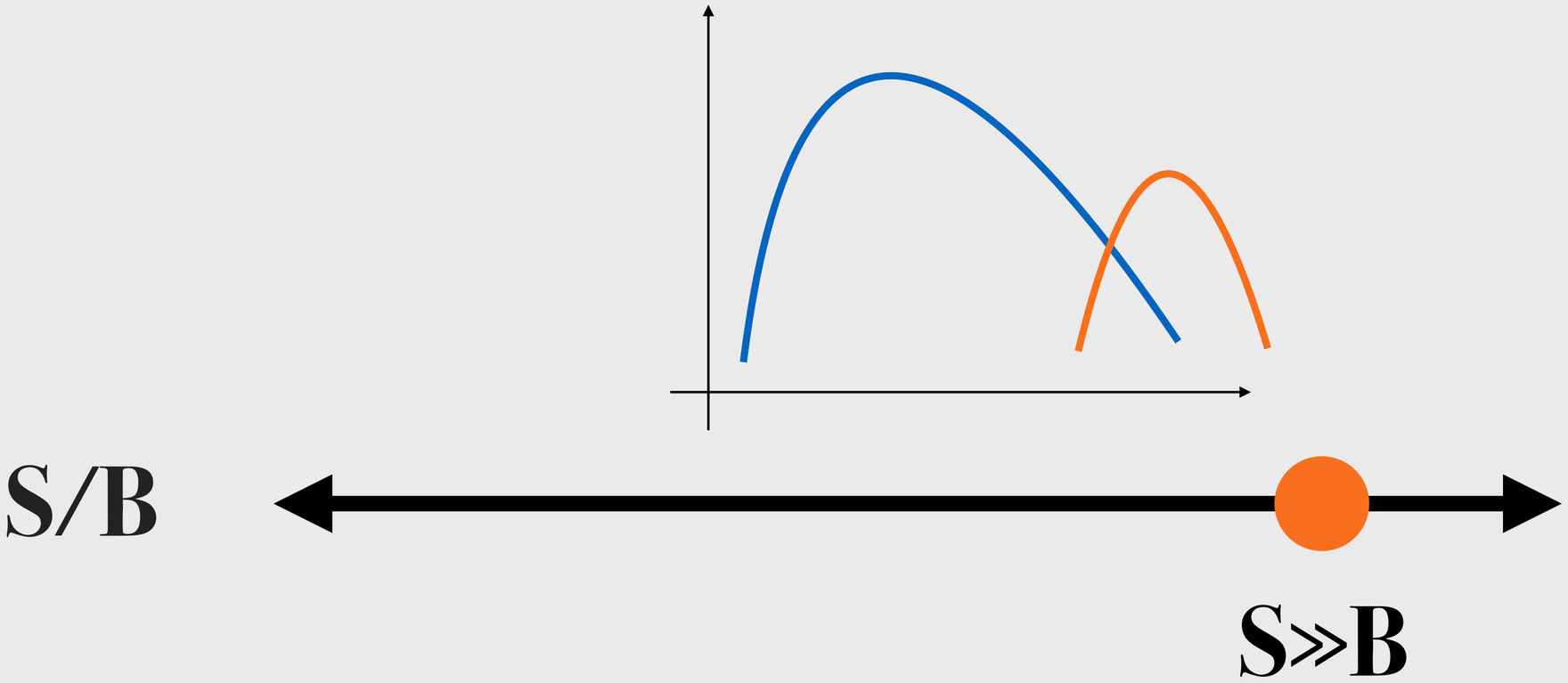
New Physics In The "Top Quark Sample"

RF - in preparation

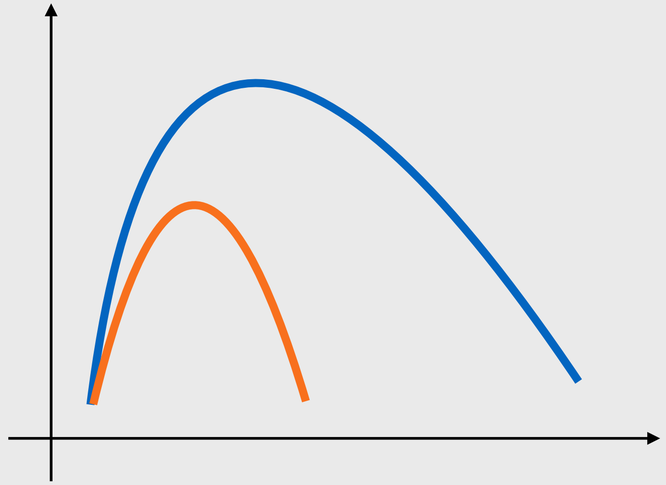
Why Top Quarks?

- Motivated in many BSM scenarios (hierarchy problem)
- NLO+PS and NNLO precision recently achieved for differential distributions *
- Blindspots of SUSY due to top quark background

Search Approach



Search Approach

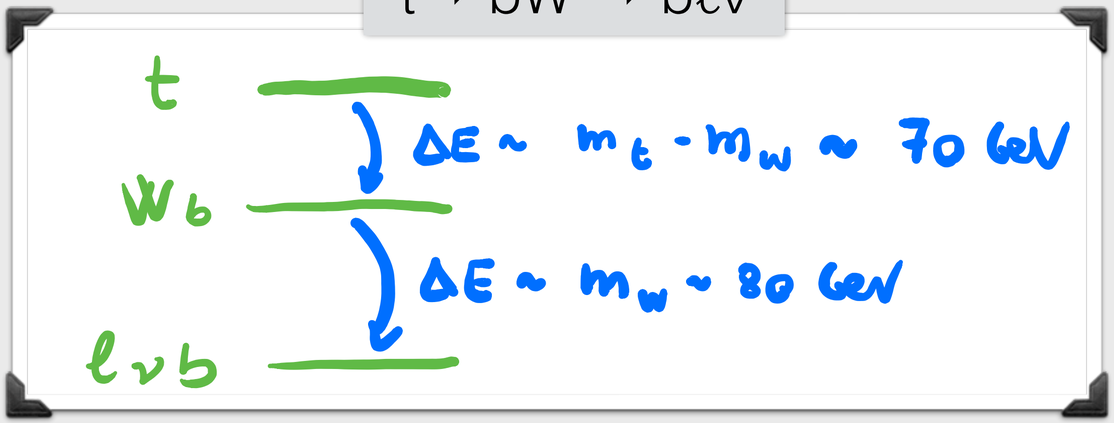


S/B

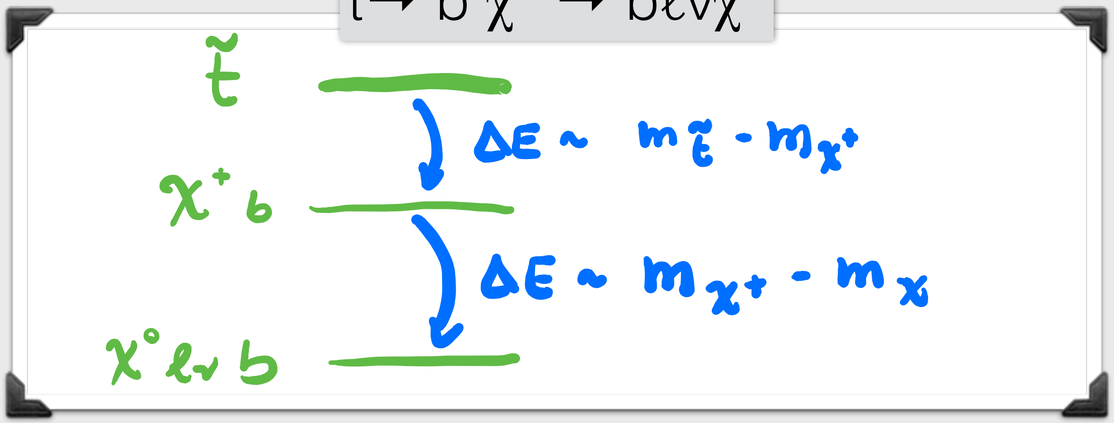
S≲B

Soft Is Hard

$t \rightarrow bW \rightarrow b\ell\nu$

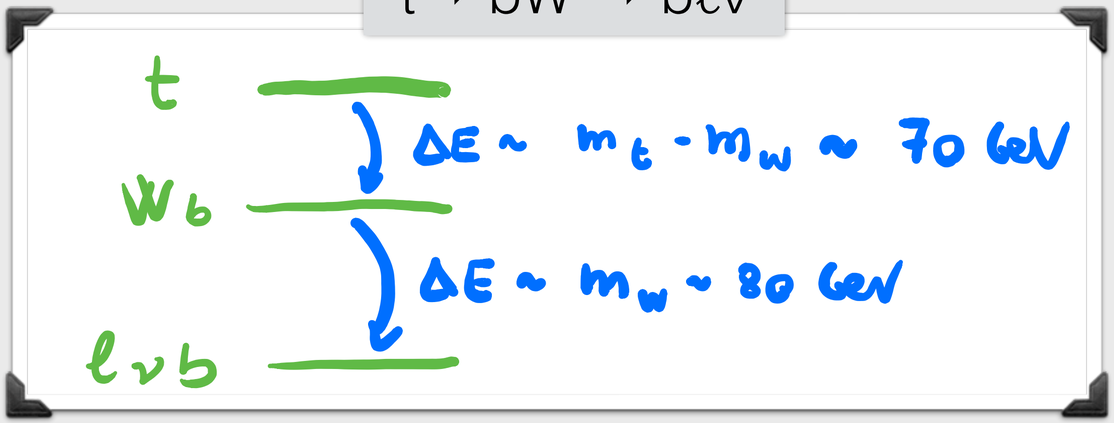


$\tilde{t} \rightarrow b\,\chi^+ \rightarrow b\ell\nu\chi^0$

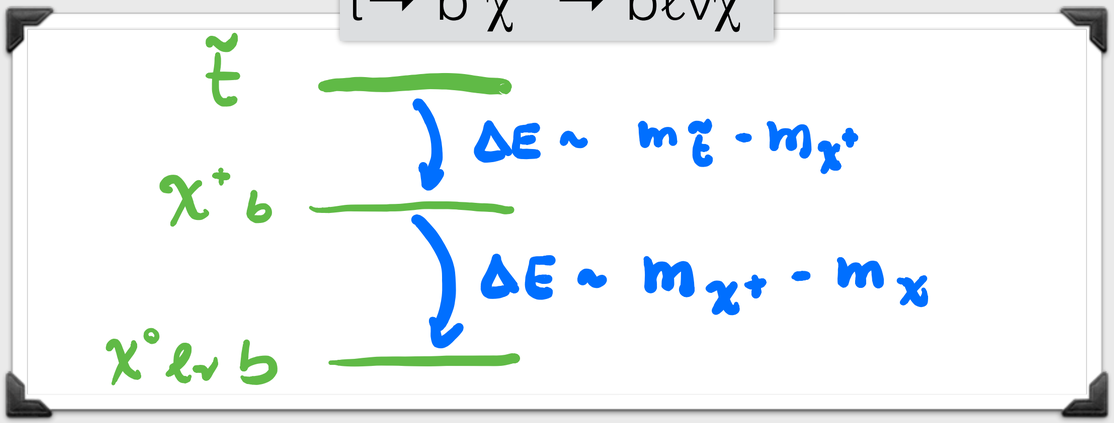


Soft Is Hard

$t \to bW \to b\ell\nu$



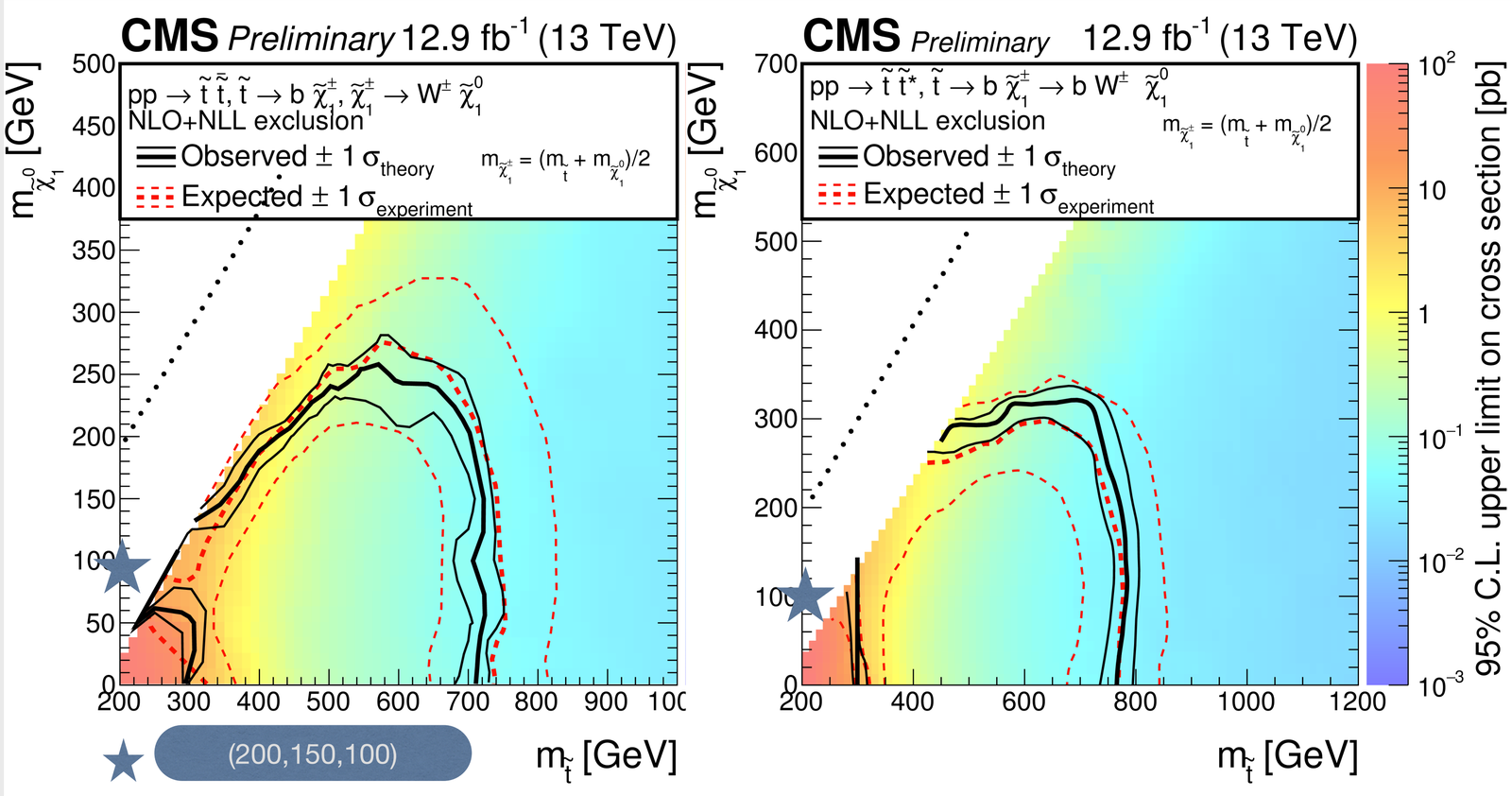
$\tilde{t} \to b\,\chi^+ \to b\ell\nu\chi^0$

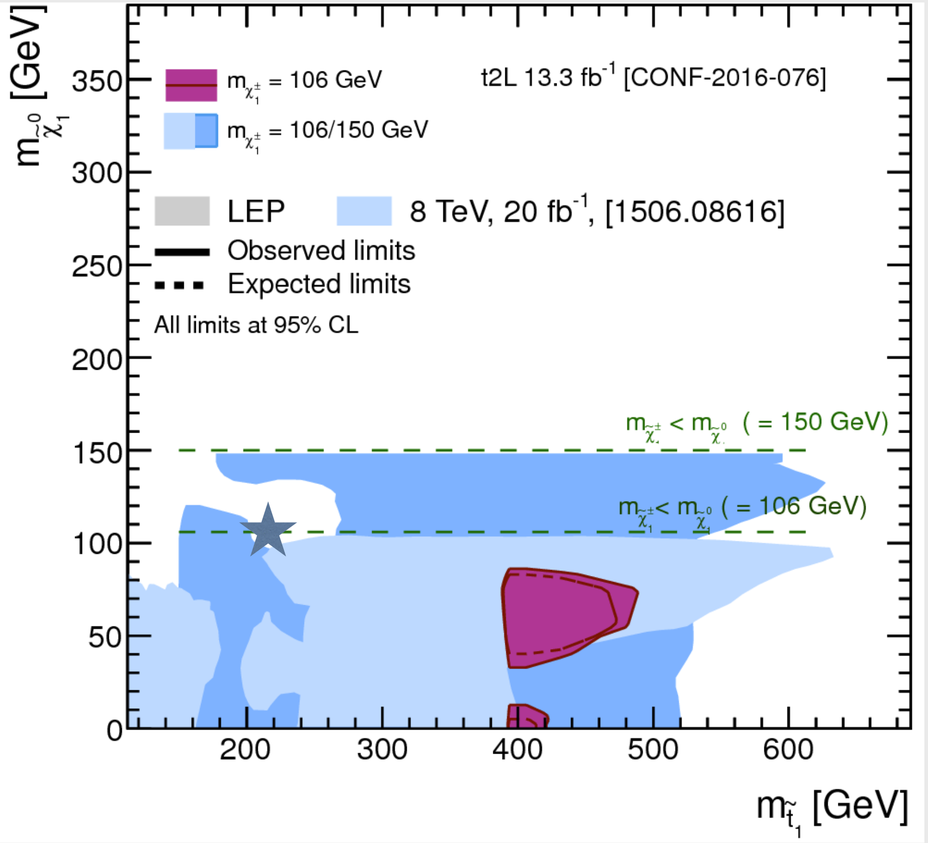


NEW PHYSICS IS SM-LIKE

BETTER PRECISION

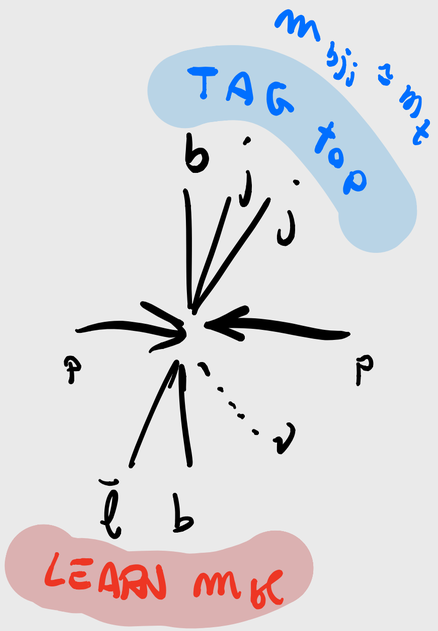
The $\{\tilde{t}, \tilde{\chi}^{+}, \tilde{\chi}^{0}\}=\{200,150,100\}$ GeV blindspot

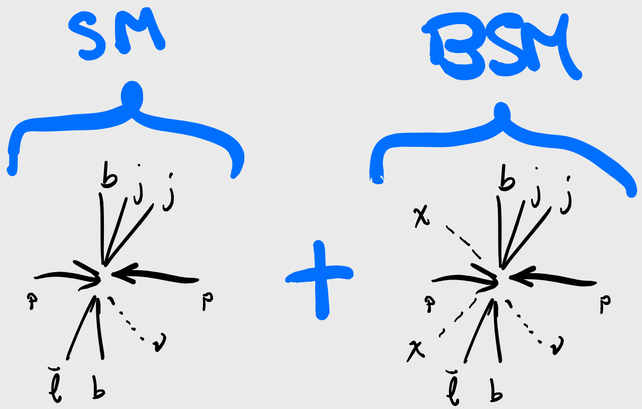


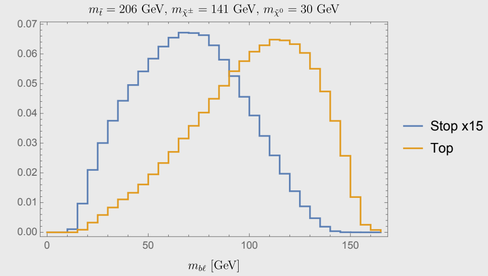


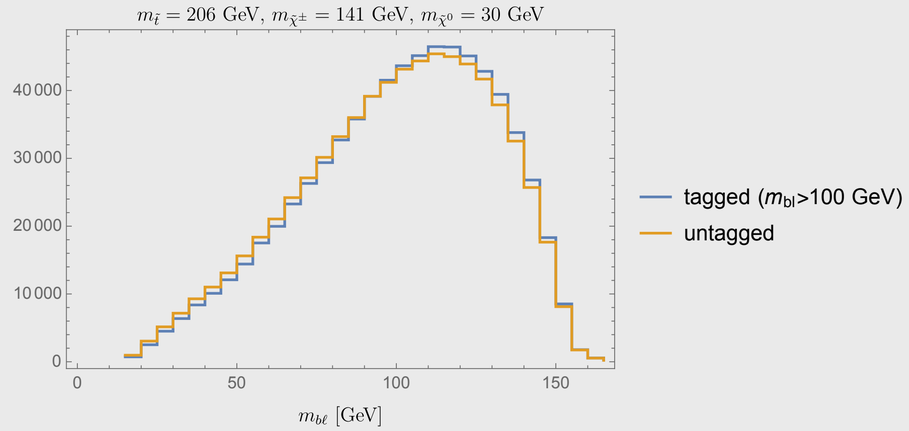
Tag the Top, Search the Stop

$\{\tilde{t}, \tilde{\chi}^+, \tilde{\chi}^0\} = \{200, 140, 30\}$ GeV



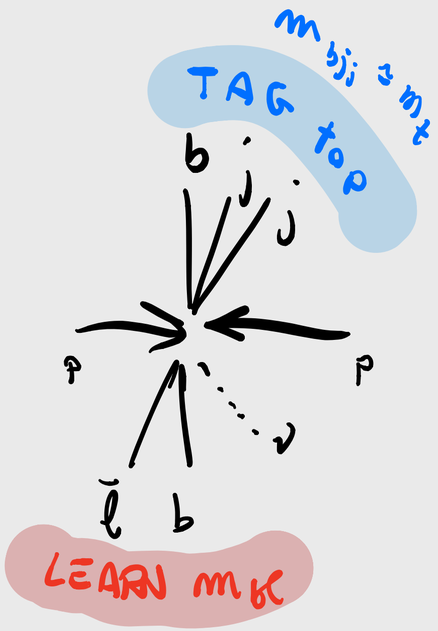


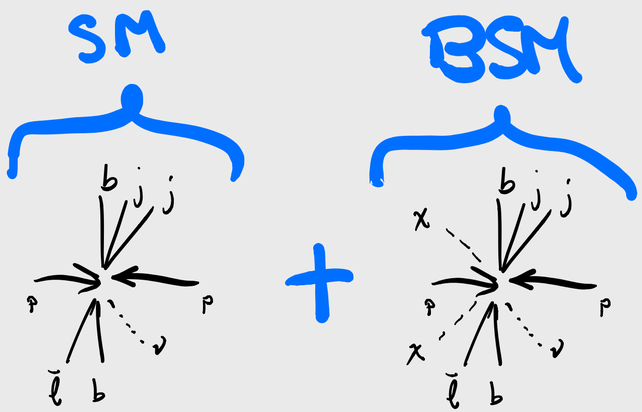


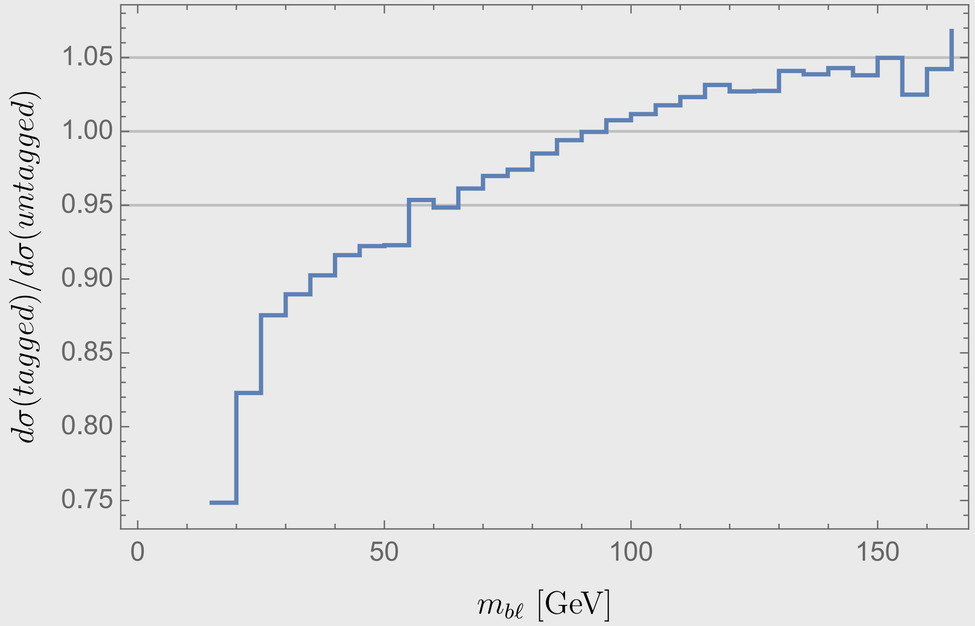


Tag the Top, Search the Stop

$\{\tilde{t}, \tilde{\chi}^+, \tilde{\chi}^0\} = \{200, 140, 30\}$ GeV







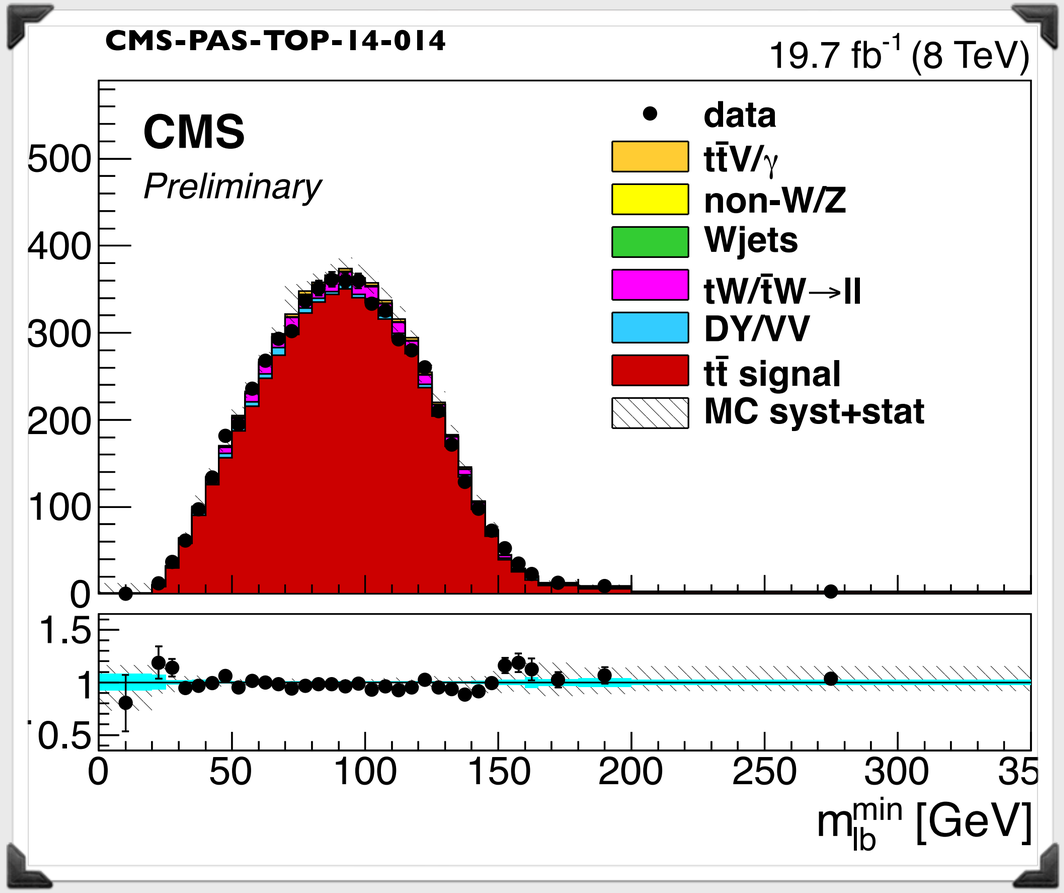
CL of exclusion

Threshold for m_{bl^+} and $m_{\bar{b}l^+}$

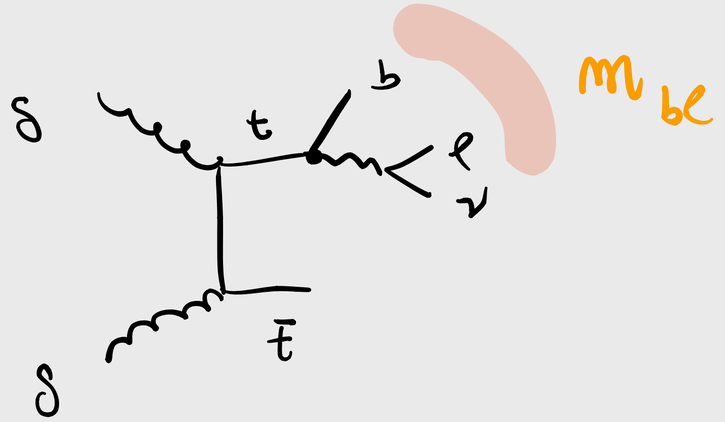
$\frac{\epsilon_{mispair}}{\epsilon_{correct}}$	m_{bl}>0 GeV	m_{bl}>20 GeV	m_{bl}>40 GeV	m_{bl}>60 GeV	m_{bl}>80 GeV	m_{bl}>100 GeV	m_{bl}>120 GeV	m_{bl}>140 GeV
0.	0	0	0	0.03	1.	1.	1.	1.
0.2	0	0	0	0	0.26	1.	1.	1.
0.4	0	0	0	0	0.02	0.51	0.77	0.77
0.6	0	0	0	0	0	0.1	0.22	0.29
0.8	0	0	0	0	0	0.011	0.026	0.061
1.	0	0	0	0	0	0	0	0.011

Tag the Top, Search the Stop

PRECISION AT THE LHC



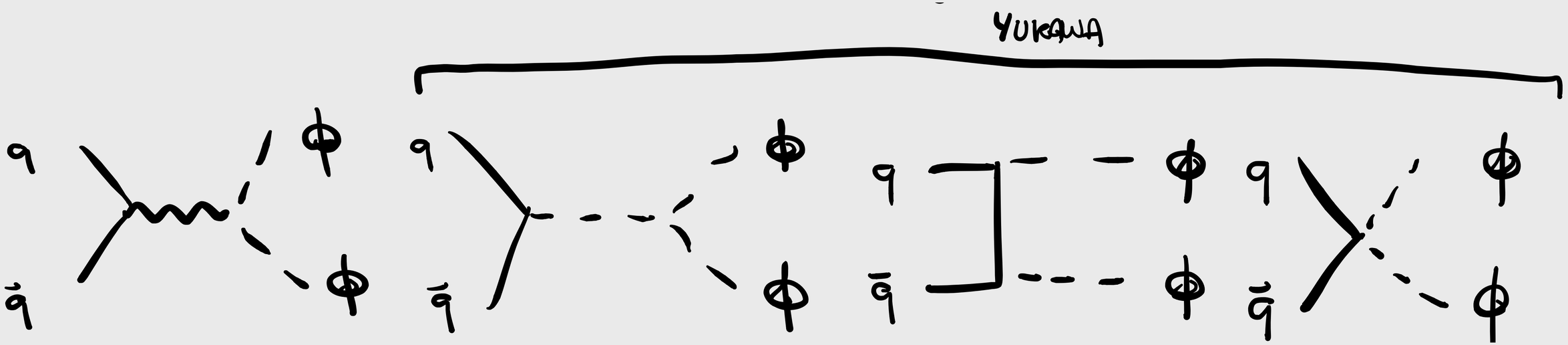
- NLO and NNLO precision top quark physics is a reality
- SM precision predictions for many observables
- Useful *per se*
- Can show deviations from SM in subtle features



m(bℓ) and other observables used in precision top quark physics can probe still uncovered new physics scenarios

High energy “primary” effects

ENCAPSULATE **ANY** BSM EFFECTS IN FEW OBSERVABLES



High energy "primary" effects

ENCAPSULATE **ANY** BSM EFFECTS IN FEW OBSERVABLES

$$|A + \delta A|^2$$

$$\delta A^{q_h \bar{q}_h \to \phi\phi}_{J=1} = \boxed{\#} \left[\sin\vartheta \cdot \overbrace{f(\varphi)}^{1} \cdot \frac{s}{\Lambda^2} \right]$$

High energy "primary" effects

ENCAPSULATE **ANY** BSM EFFECTS IN FEW OBSERVABLES

$$A^{hZ}_{u_R \bar{u}_R} = A^{W^+W^-}_{u_R \bar{u}_R} = a_u \qquad A^{hZ}_{d_L \bar{d}_L} = A^{W^+W^-}_{u_L \bar{u}_L} = a^{(1)} - a^{(3)}$$

$$A^{hZ}_{d_R \bar{d}_R} = A^{W^+W^-}_{d_R \bar{d}_R} = a_d \qquad A^{hZ}_{u_L \bar{u}_L} = A^{W^+W^-}_{d_L \bar{d}_L} = a^{(1)} + a^{(3)}$$

$$|A + \delta A|^2$$

$$\delta A^{q_h \bar{q}_h \to \phi\phi}_{J=1} = \# \left[\sin\vartheta \cdot \overbrace{f(\varphi)}^{1} \cdot \frac{s}{\Lambda^2} \right]$$

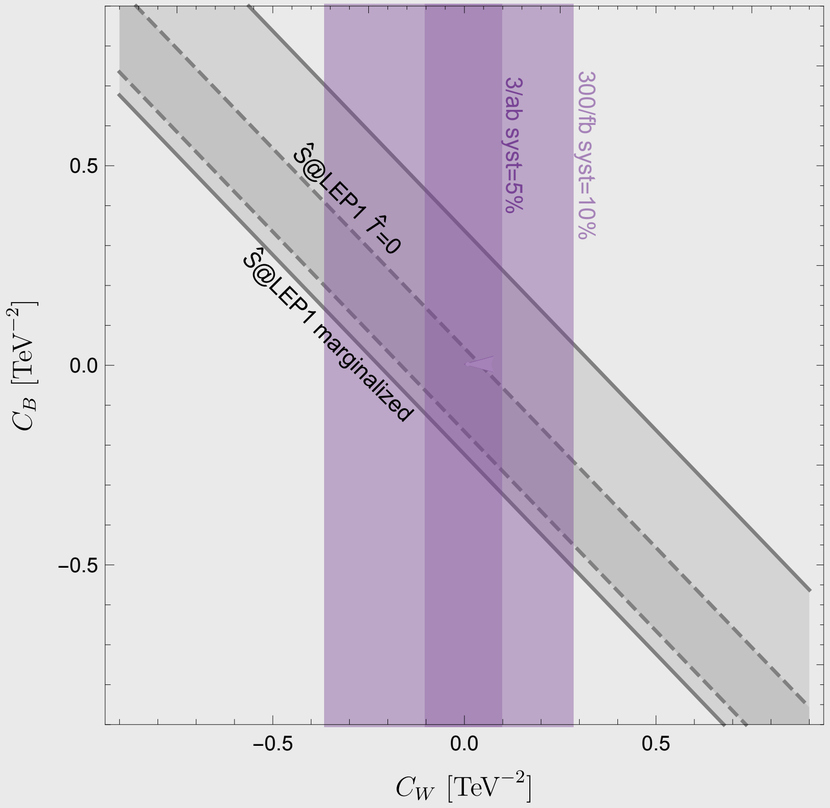
Thank You!

Leading SILH operators

$$a_q^{(1)} = \frac{g'^2}{3M^2}(c_B + c_{HB} - c_{2B}) \,,$$

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

$$c_W = c_B = \frac{27\pi^2}{256} \simeq 1.0 \,, \quad c_{HW,HB} = 0 \,, \quad c_{2B,2W} \simeq \frac{g^2}{g_*^2} \ll 1 \,,$$



@&2CHM&V3

CHM~UNIVERSAL

$$c_W \simeq c_B \simeq 1\,, \quad c_{HW,HB} \simeq 0\,, \quad c_{2B,2W} \simeq \frac{g^2}{g_*^2} \ll 1\,,$$

$$\mathcal{L}_{\rm int} = \frac{1}{2} W'^a_\mu \left[g_f \bar{f}_L \gamma^\mu \sigma^a f_L + i g_H H^\dagger \sigma^a \overleftrightarrow{D}^\mu H \right] .$$

$$a_q^{(3)} = \frac{3g^2}{g'^2} a_q^{(1)} = \frac{g^2}{M^2}\,, \quad a_q^{(3)} m_W^2 = -g^2 c_{\theta_W}^2 \delta g_1^Z = \frac{g^2}{2} \hat{S}\,.$$

$$a_q^{(3)} = -\frac{g_q g_H}{M^2}\,, \quad a_q^{(1)} = a_u = a_d = 0\,,$$

Low energy primary effects

$$a_q^{(1)} = \frac{g'^2}{3m_W^2}\left(\hat{S} - \delta\kappa_\gamma + c_{\theta_W}^2 \delta g_1^Z - Y\right) ,$$

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