Profiling Z' bosons using asymmetry observables in top pair production with the lepton-plus-jets final state at the LHC

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12th July 2016

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- Leads to additional term in low-energy neutral current Lagrangian:

$$\mathcal{L} \supset g' Z'_\mu \bar{f} \gamma^\mu (c_V^f - c_A^f \gamma_5) f = g' Z'_\mu \bar{f} \gamma^\mu Q_{Z'} f .$$

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- E_6 inspired models:

$$\begin{aligned} \mathrm{E}_6 &\to \mathrm{SO}(10) \times \mathrm{U}(1)_\psi \\ \mathrm{SO}(10) &\to \mathrm{SU}(5) \times \mathrm{U}(1)_\chi \\ \mathrm{SU}(5) &\to \mathrm{SU}(3)_C \times \mathrm{SU}(2)_L \times U(1)_Y. \end{aligned}$$

$$Q_{E_6} = \cos\theta T_\chi + \sin\theta T_\psi.$$

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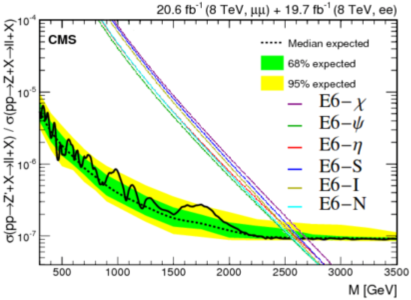

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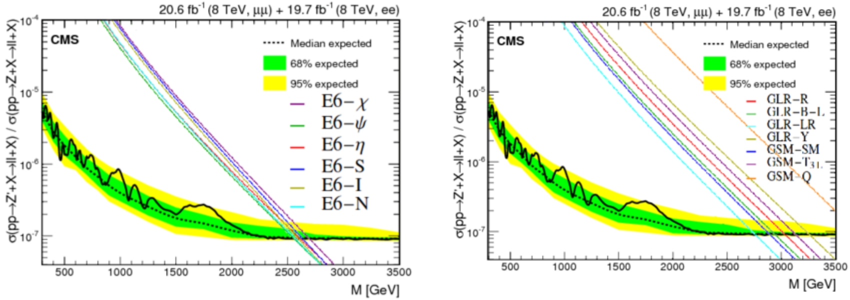

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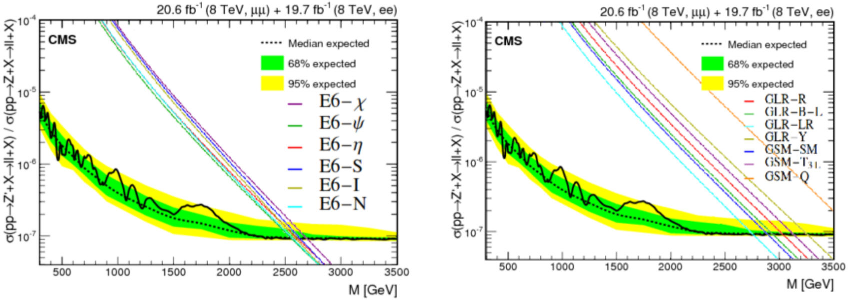

Class	E_6						GLR				GSM		
$U(1)'$	χ	ψ	η	S	I	N	R	BL	LR	Y	SM	T_L^3	Q
$M_{Z'}$	2700	2560	2620	2640	2600	2570	3040	2950	2765	3260	2900	3135	3720

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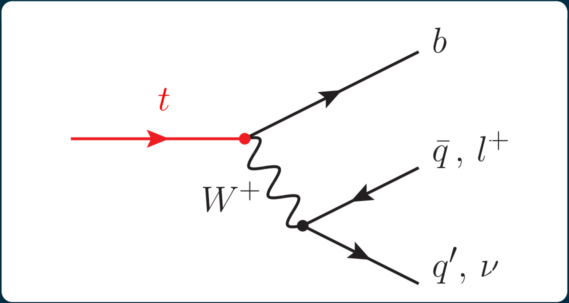

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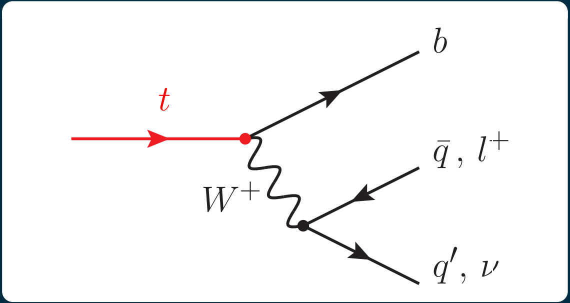

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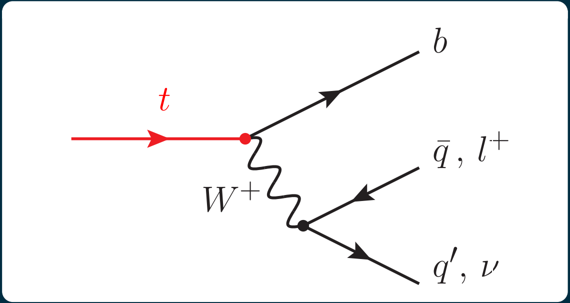

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- Allows definition of unique Asymmetry observables.

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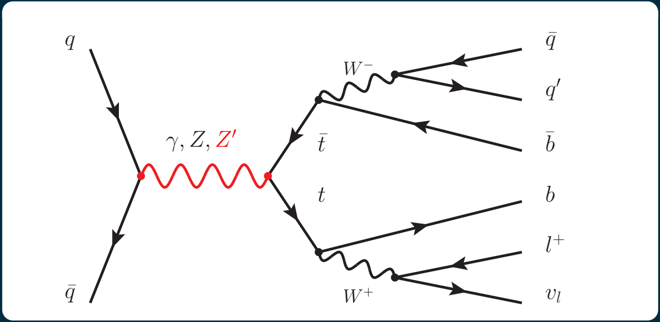

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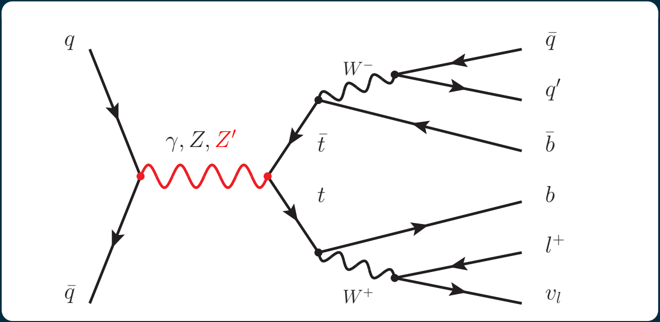

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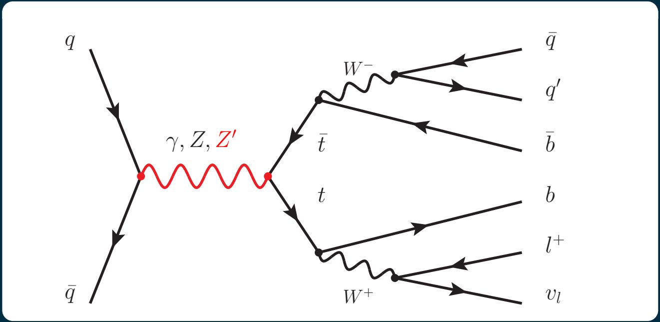

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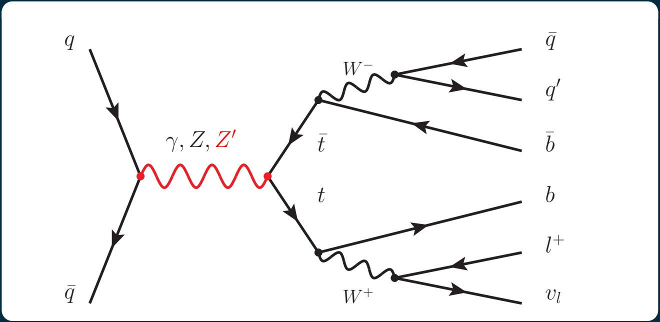

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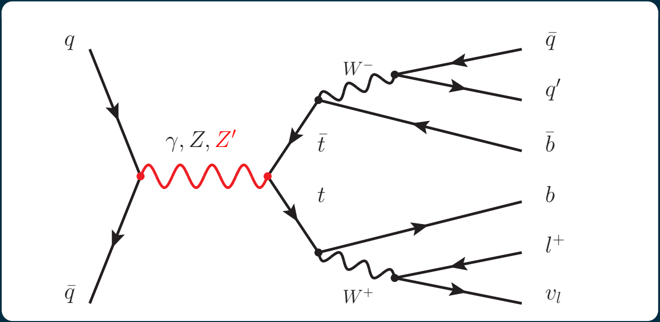

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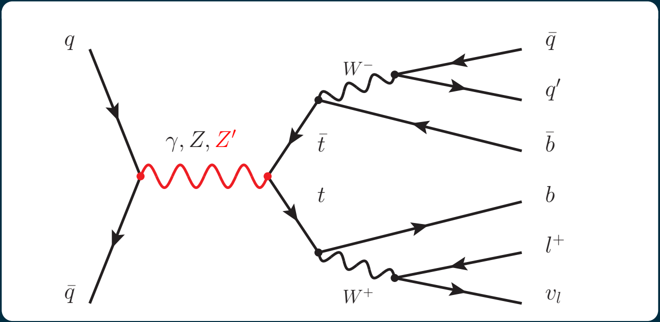

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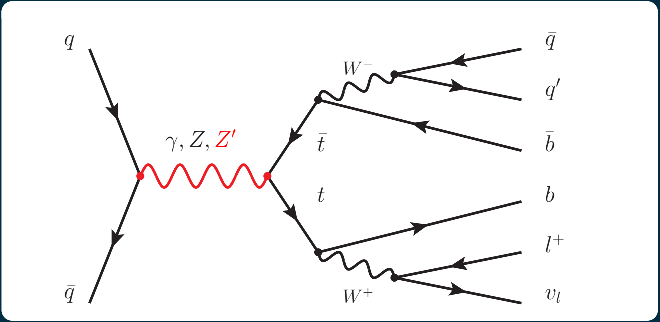

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- VEGAS for multi-dimensional numerical phase-space integration.

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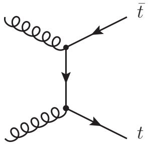

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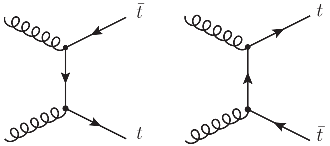

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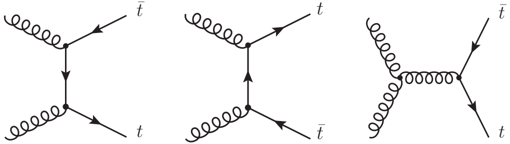

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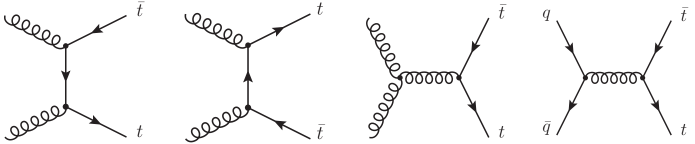

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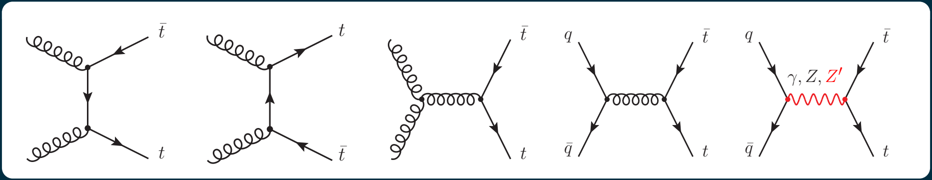

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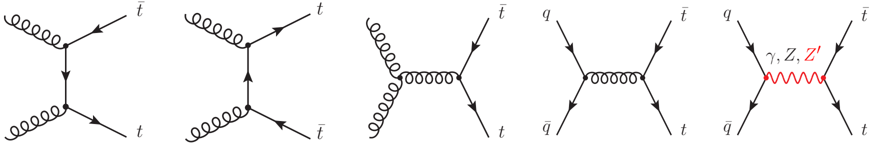

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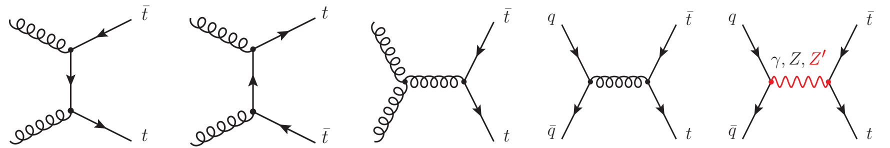

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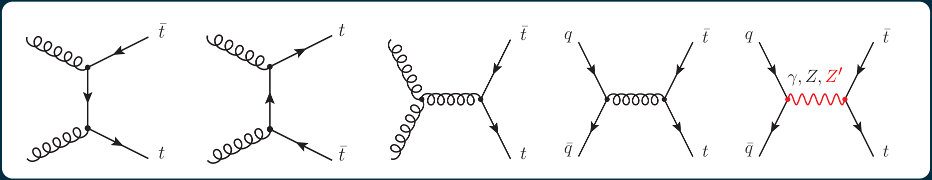

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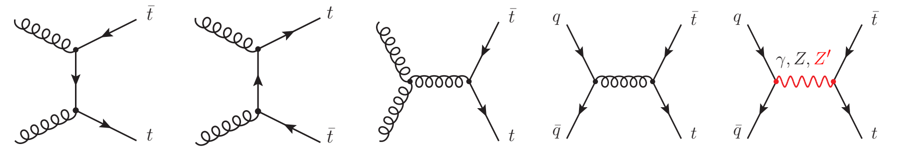

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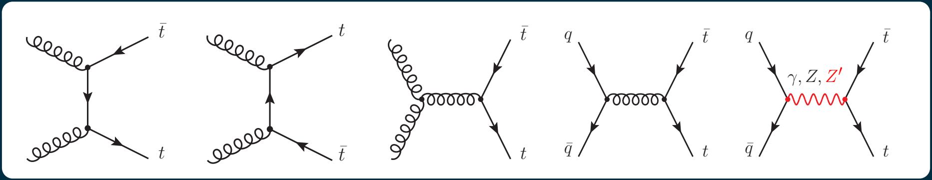

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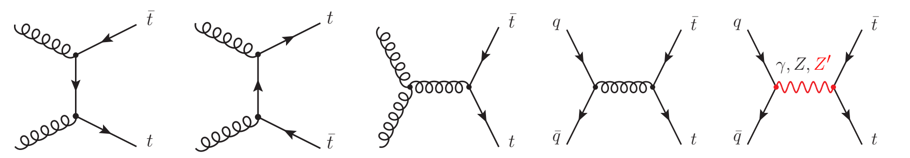

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$$D^{ij} = \frac{(\hat{s}-m_i^2)(\hat{s}-m_j^2) + m_i m_j \Gamma_i \Gamma_j}{\left((\hat{s}-m_j^2)^2 + m_i^2\Gamma_i^2\right)\left((\hat{s}-m_j^2)^2 + m_j^2\Gamma_j^2\right)}.$$

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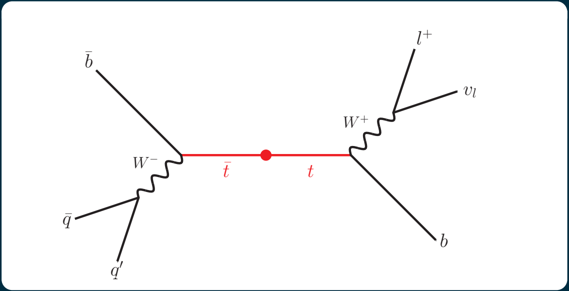

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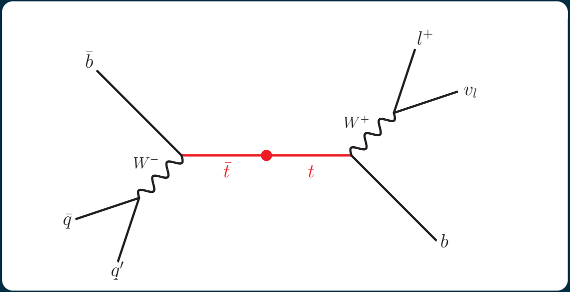

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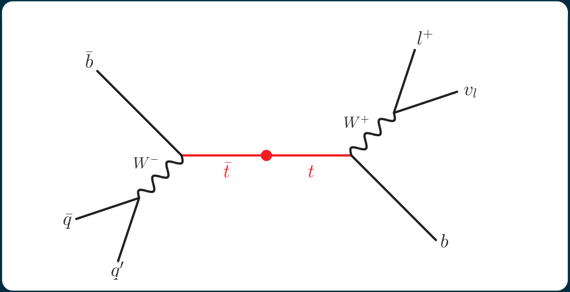

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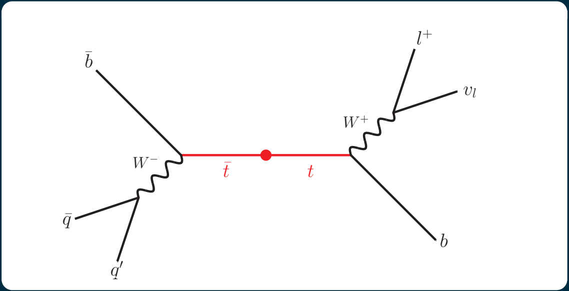

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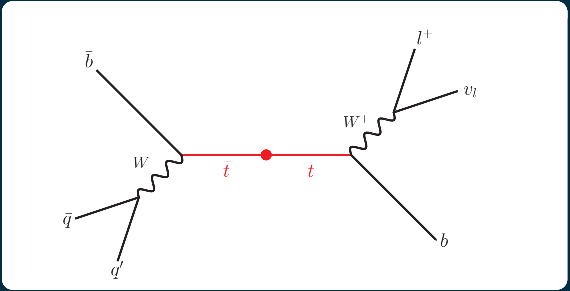

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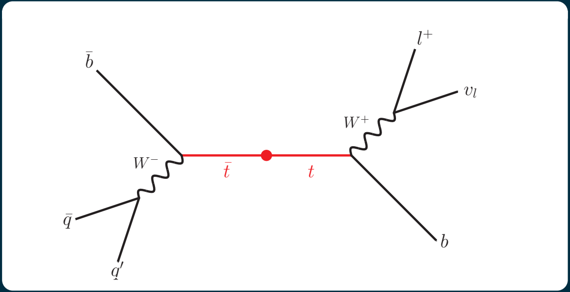

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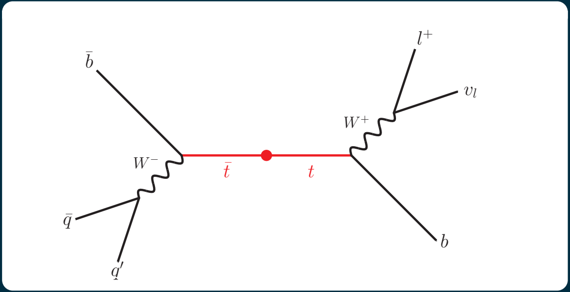

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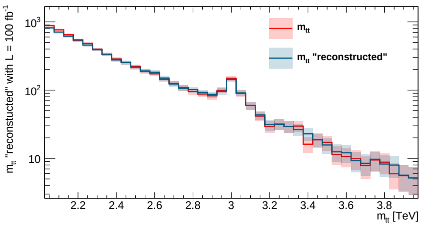

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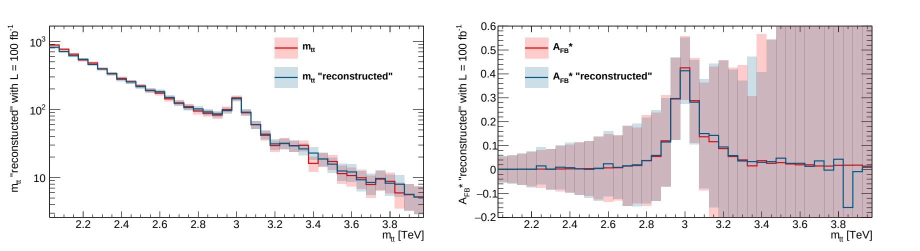

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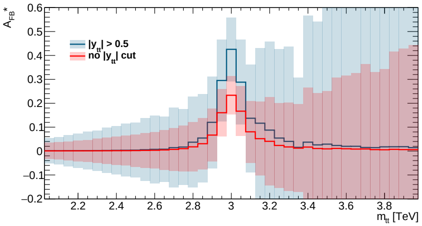

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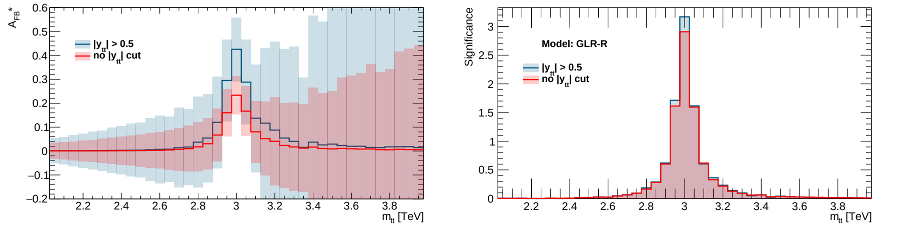

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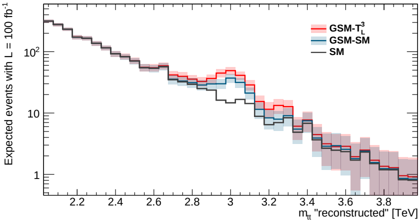

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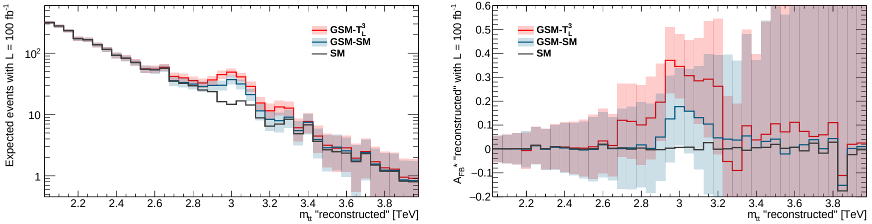

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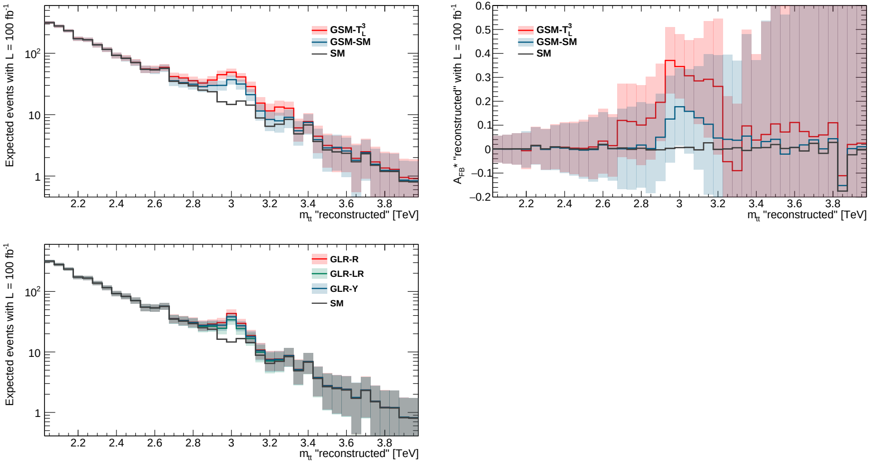

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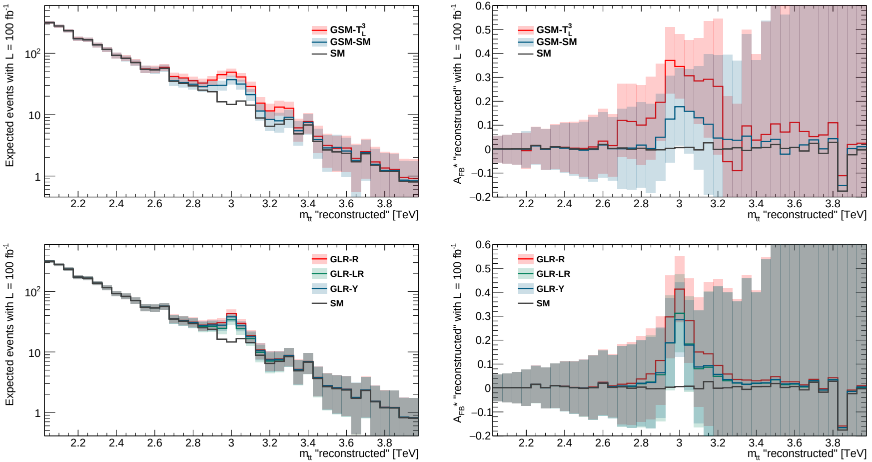

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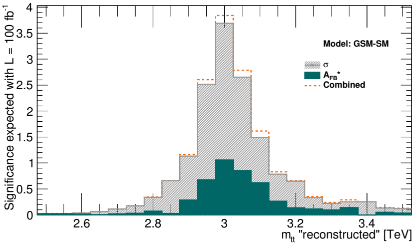

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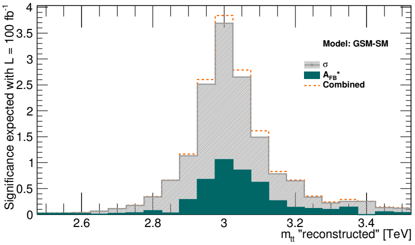

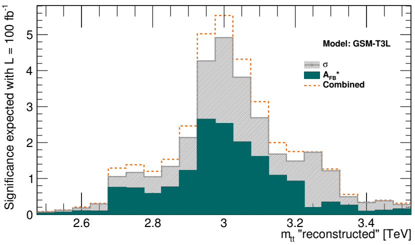

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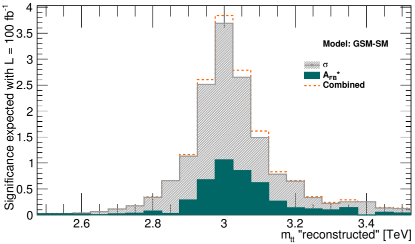

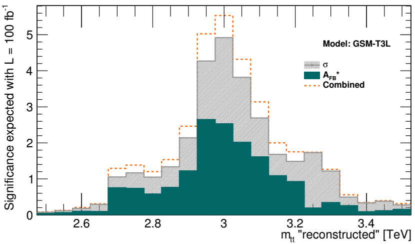

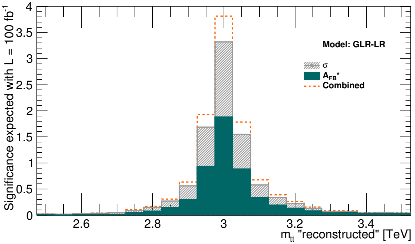

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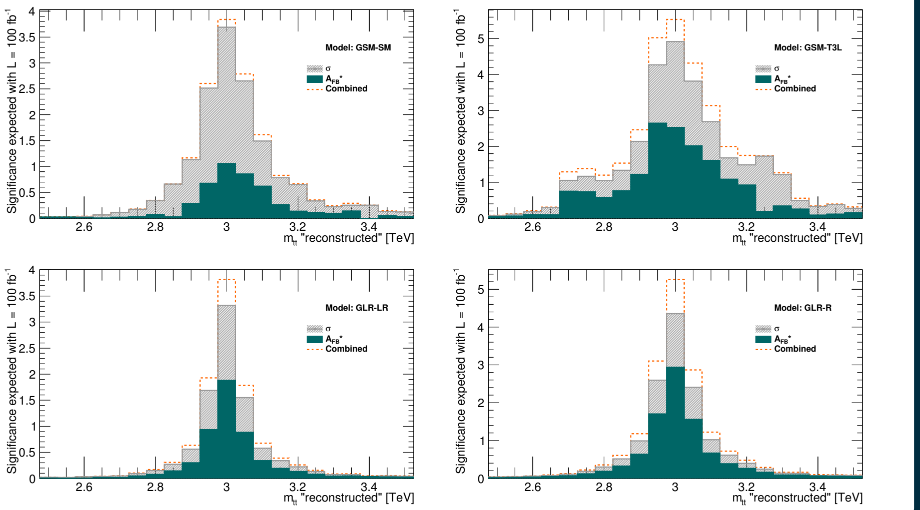

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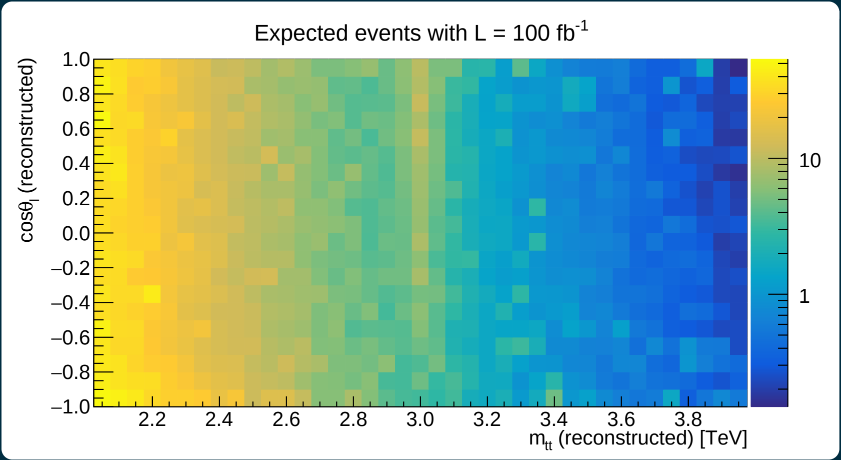

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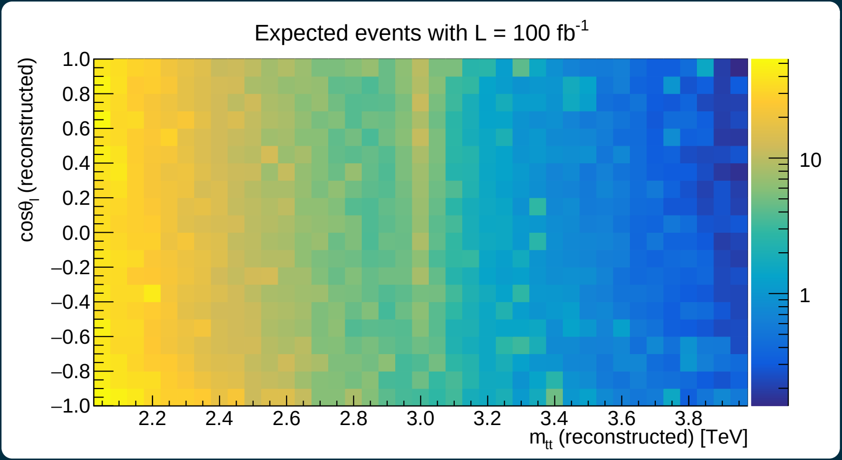

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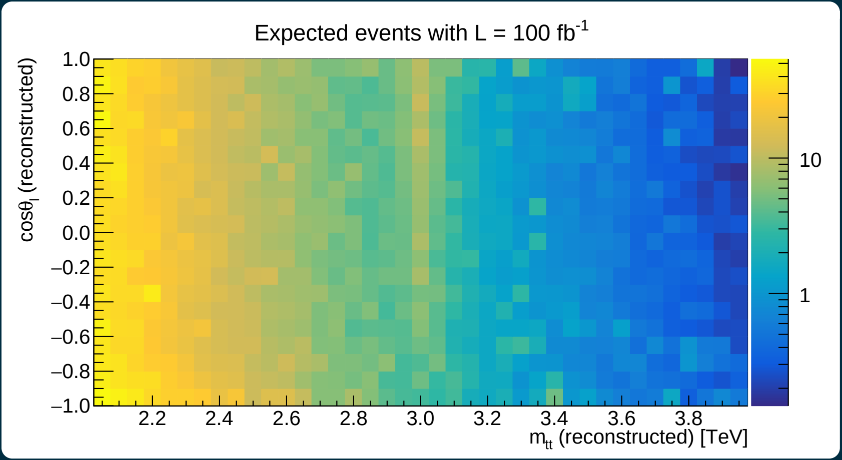

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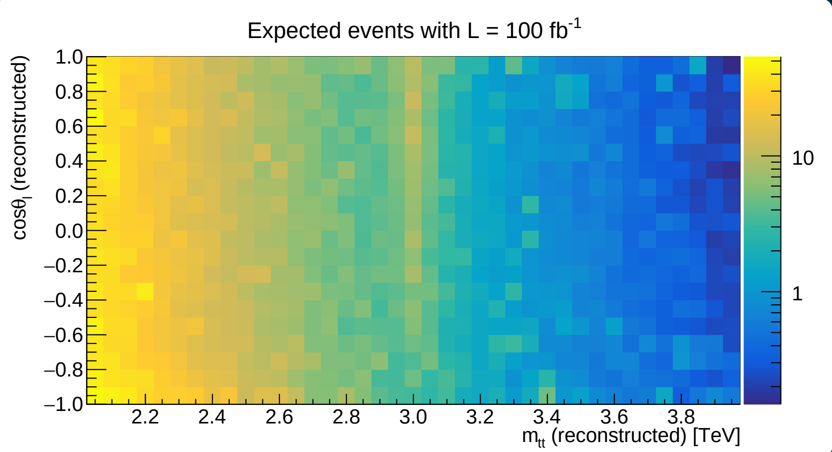

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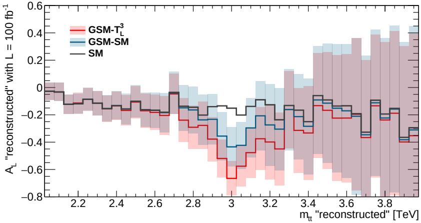

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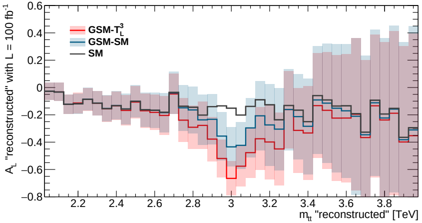

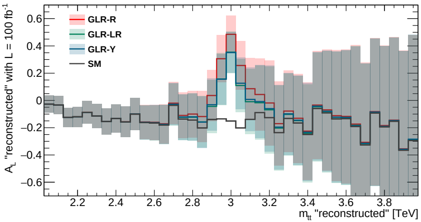

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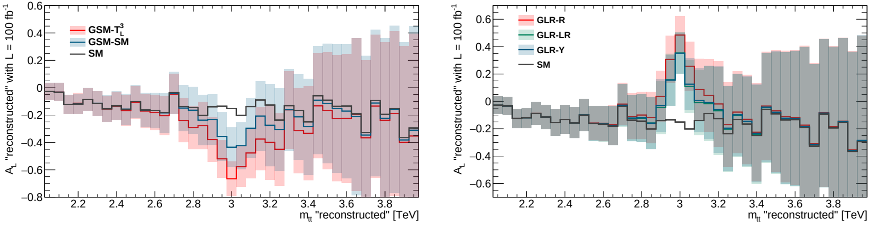

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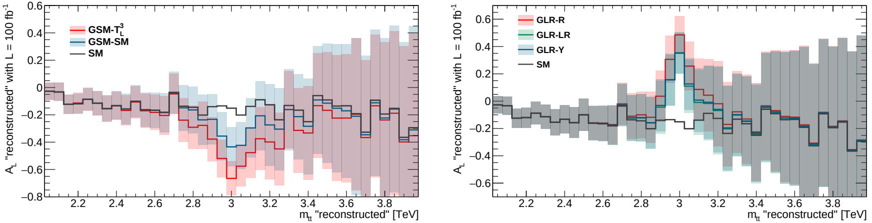

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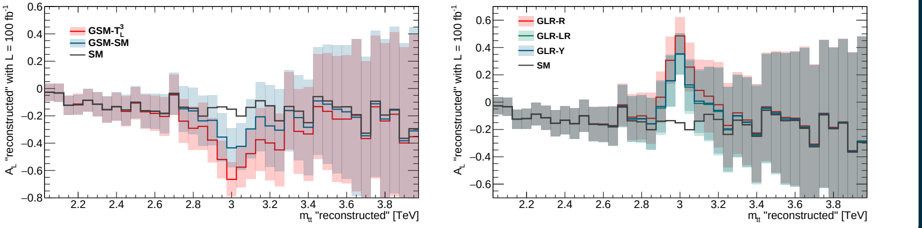

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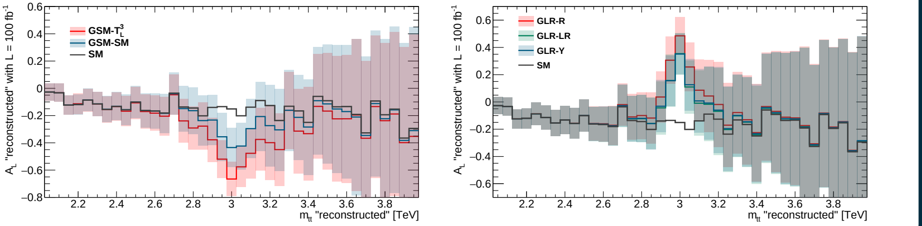

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- In reality this process would fall in the boosted regime: we could not resolve individual jets.

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- Investigate other angularly dependent variables that may be constructed for di-leptonic $t\bar{t}$ events.

Thanks for listening!

Backup slides

Z' boson parameters

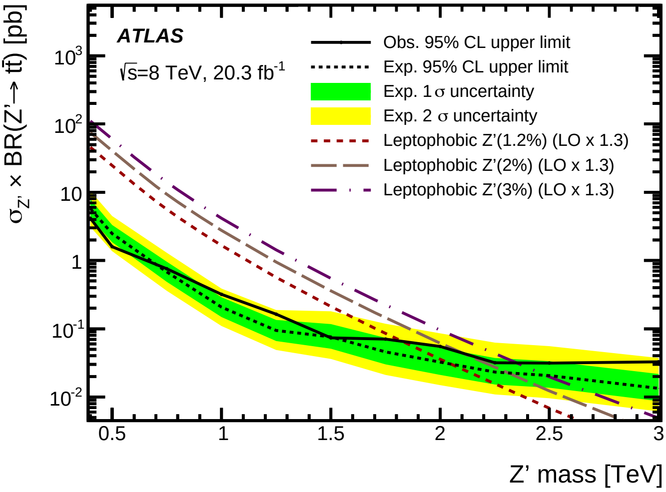
- Width determined by

$$\Gamma(Z' \to f\bar{f}) = N_c \frac{g_{Z'}^2 m_{Z'}}{48\pi} \beta \left[\frac{3 - \beta^2}{2} {c_V}^2 + \beta^2 {c_A}^2 \right],$$

- where

$$\beta = \sqrt{1 - 4\frac{m_f^2}{m_{Z'}^2}}.$$

Experimental bounds from ATLAS - lepton plus jets



Benchmark model Z' parameters and couplings

$U(1)'$	Parameter	g_V^u	g_A^u	g_V^d	g_A^d
E_6 (g'=0.462)	θ				
$U(1)_\chi$	0	0	-0.316	-0.632	0.316
$U(1)_\psi$	0.5π	0	0.408	0	0.408
$U(1)_\eta$	-0.29π	0	-0.516	-0.387	0.129
$U(1)_S$	0.129π	0	-0.129	-0.581	0.452
$U(1)_N$	0.42π	0	-0.316	-0.158	0.474
G_{LR} (g'=0.595)	ϕ				
$U(1)_R$	0	0.5	-0.5	-0.5	0.5
$U(1)_{B-L}$	0.5π	0.333	0	-0.333	0
$U(1)_{LR}$	-0.128π	0.329	-0.46	-0.591	0.46
$U(1)_Y$	0.25π	0.589	-0.353	-0.118	0.354
G_{SM} (g'=0.760)	α				
$U(1)_{SM}$	-0.072π	0.193	0.5	-0.347	-0.5
$U(1)_{T_{3L}}$	0	0.5	0.5	-0.5	-0.5
$U(1)_Q$	0.5π	1.333	0	-0.666	0

Asymmetries with polarized stable tops

- Spatial/spin asymmetries categorize events:

$$A = \frac{N_A - N_B}{N_A + N_B}$$

- At the polarised top level we can define a number of variables, e.g.

$$A_{FB} = \frac{N(\cos\theta > 0) - N(\cos\theta < 0)}{N(\cos\theta > 0) + N(\cos\theta < 0)}$$

$$A_{LL} = \frac{N(+,+) + N(-,-) - N(+,-) - N(-,+)}{N(+,+) + N(-,-) + N(+,-) + N(-,+)},$$

$$A_L = \frac{N(+,+) + N(+,-) - N(-,+) - N(-,-)}{N(+,+) + N(+,-) + N(-,+) + N(-,-)},$$

Significance

- Construct likelihood:

$$L(\mu, \theta) = \sum_{j=1}^{N} \frac{(\mu s_j + b_j)^{n_j}}{n_j} e^{-(\mu s_j + b_j)} \sum_{k=1}^{M} \frac{u_k^{m_k}}{m_k!} e^{-u_k} \qquad (3)$$

- Find profile likelihood ratio:

$$\lambda(\mu) = \frac{L(\mu, \hat{\hat{\theta}})}{L(\hat{\mu}, \hat{\theta})} \qquad (4)$$

- Set $\mu = 0$ hypothesis - set $\mu = 0$, i.e. assume that there is no new physics contribution, derive distribution with toys/asymptotic
- Code is available in RootStats.
- See arXiv:1007.1727v3.

Liklihood for asymmetry and m_{tt}

- Mean expected number of events in a given m_{tt} (i) and $\cos\theta^*$ (j) bin.

$$\nu(i,j)(\mu,\sigma_{t\bar{t}},\sigma_{Z'},\theta) = L[\epsilon_{t\bar{t}}(i,j,\theta)\sigma_{t\bar{t}} + \alpha_{Z',t\bar{t}}(i,j,\theta)\mu(\sigma_{Z'} + \sigma_{int(Z',t\bar{t})})] \quad (5)$$

- L for the above is the luminosity. ϵ and α represent the efficiencies for SM background and for signal to fall in the given bin: asymmetry*detector.
- Observed number of events

$$\mathcal{L}(N(i,j)|\mu,\sigma_{t\bar{t}},\sigma_{Z'}) = \sum_{i,j} e^{\nu(i,j)} \frac{\nu^{N(i,j)}}{N(i,j)!} \quad (6)$$

- We only use statistical uncertainty.
- We can possibly add theoretical uncertainties.