

Boosted Tops

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On-going project in collaboration with Andy Buckley & Benjamin Fuks

Top LHC France
April 7th, 2021



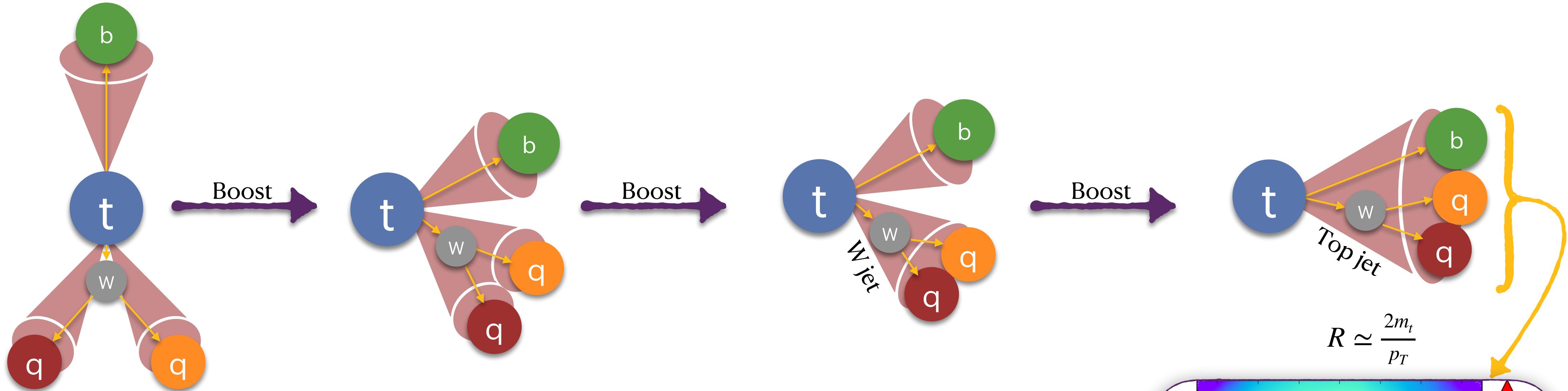
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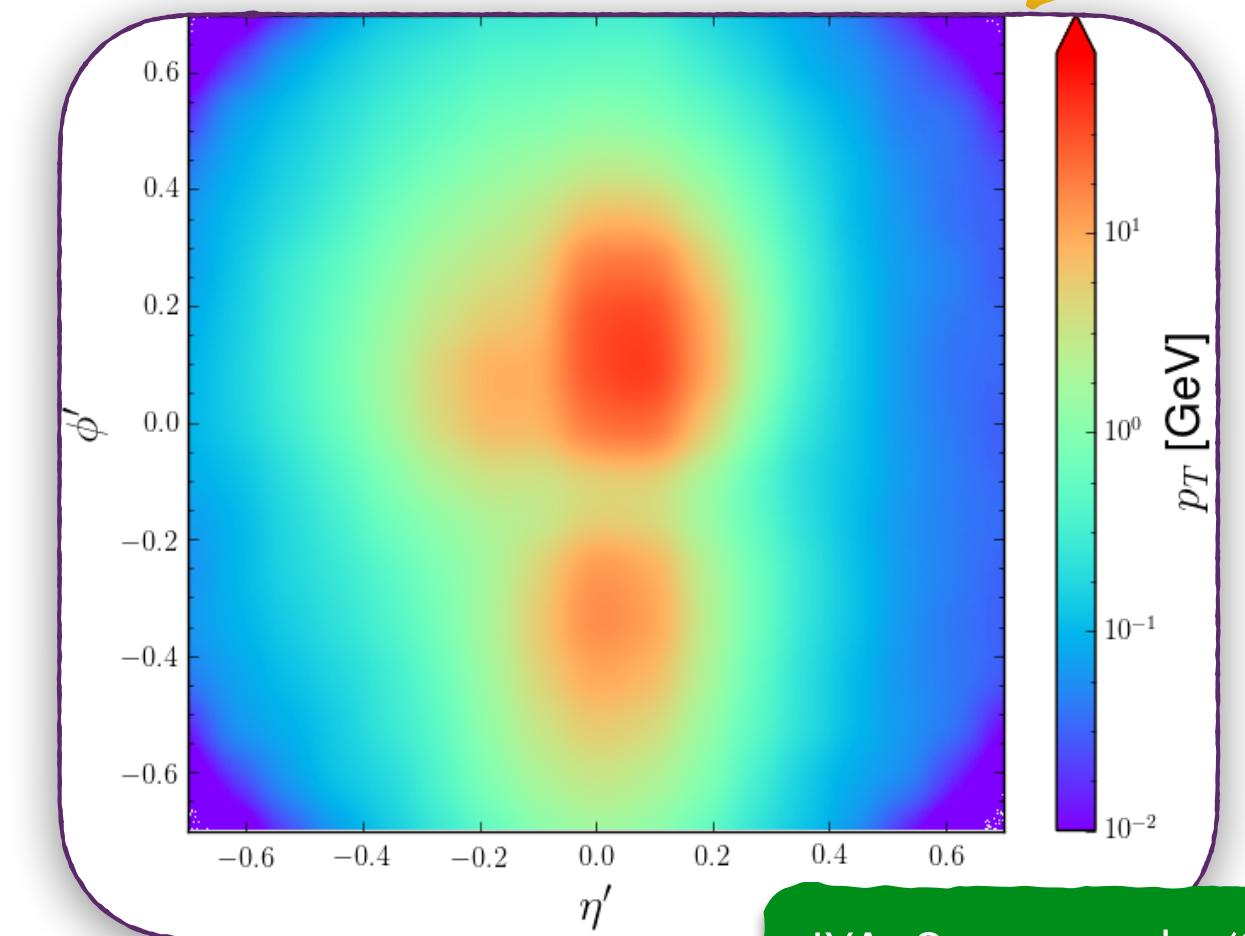
Outline

- Why boosted?
- Analysis strategy: Semi-Leptonic SR
- Top tagging efficiency
- Tagging full/on-shell $t\bar{t}$ events
- Effective Operator Sensitivities
- Conclusion

Why Boosted?



- ❖ With the increasing **boost** factor, jets (top's decay products) become more and more **collimated**.
- ❖ The contribution of the EFT operators **grows with energy**.
- ❖ Hadronic top tagging tools: Mass grooming and filtering, Pruning, Trimming, Soft Drop Tagger, Mass Drop Tagger, **HEPTopTagger**, Machine Learning
- ❖ What is the $t\bar{t}$ signal? Although the **resonance** accounts for a “physical top”, **off-shell** diagrams do contribute to this signal region which is often not included. Should off-shell contributions accounted as background? The actual background coming from $W+jets$ are quite insignificant with respect to the signal.



JYA, Spannowsky '21

Analysis Strategy: Semi-Leptonic SR

Light Jet Definition:

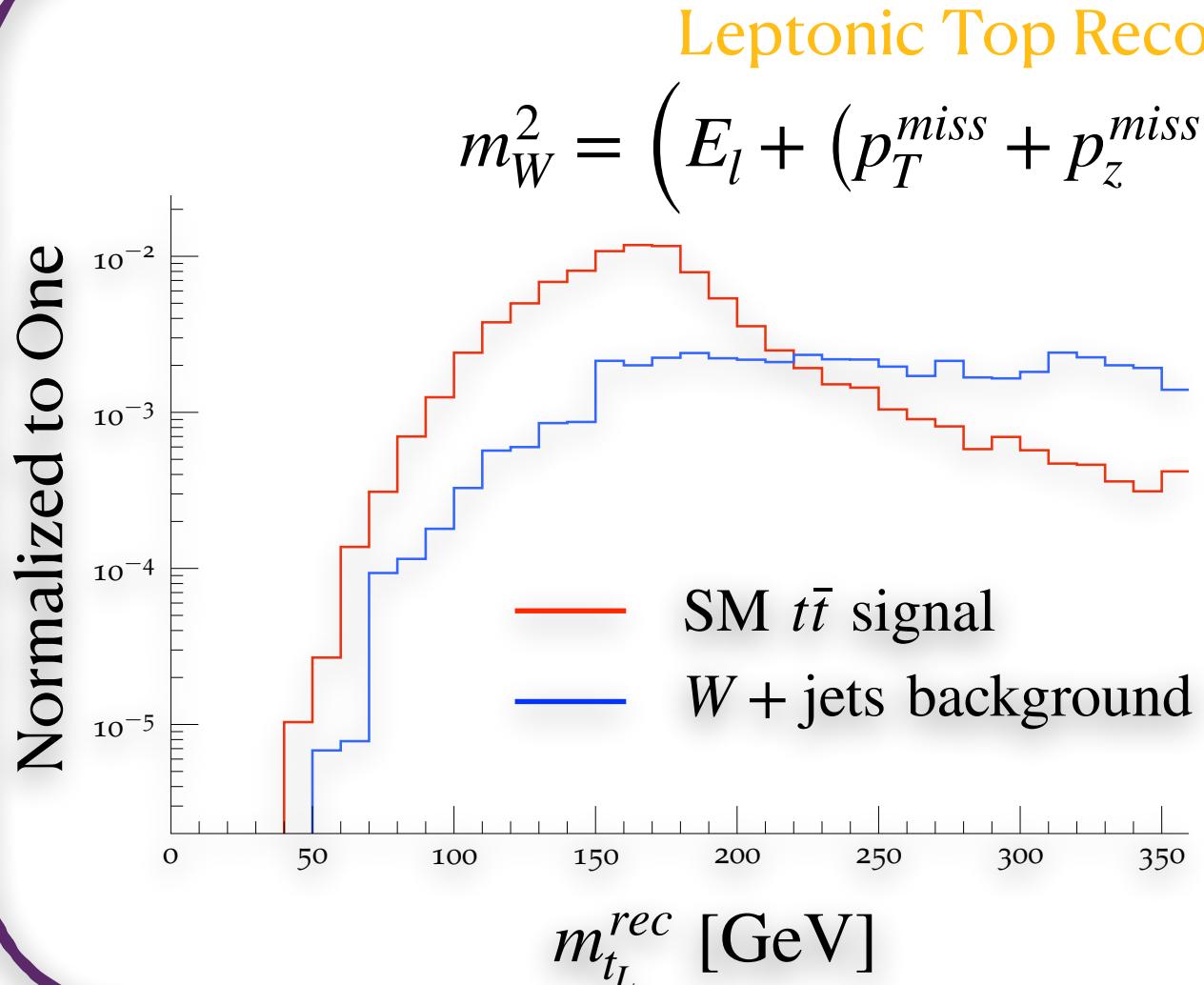
Anti- k_T Algorithm,
 $R = 0.4, p_T > 20 \text{ [GeV]}$

Fat Jet Definition:

Cambridge/Achen Algo,
 $R = 1.5, p_T > 200 \text{ [GeV]}$

Base cuts

- $N_l = 1$
- $p_T(l_1) > 30 \text{ [GeV]}$
- $N_b \geq 2$
- $N_{\text{light jets}} > 2$
- $E_T^{\text{miss}} > 30 \text{ [GeV]}$
- $N_{\text{fat-jets}} \geq 1$



Leptonic Top Reconstruction:

$$m_W^2 = \left(E_l + (p_T^{\text{miss}} + p_z^{\text{miss}}) \right)^2 - (p_i^l + p_i^{\text{miss}})^2$$

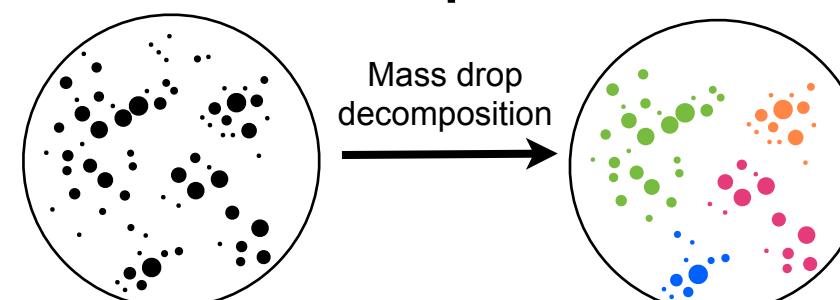
- ❖ W-mass has been reconstructed by solving m_W^2 with respect to p_z^{miss} .
- ❖ t_L^{rec} has been reconstructed by iteratively choosing b-jet which best reconstructs $m_{t_L}^{\text{rec}}$ with W^{rec} .

Plehn, Spannowsky, Takeuchi; PRD '11

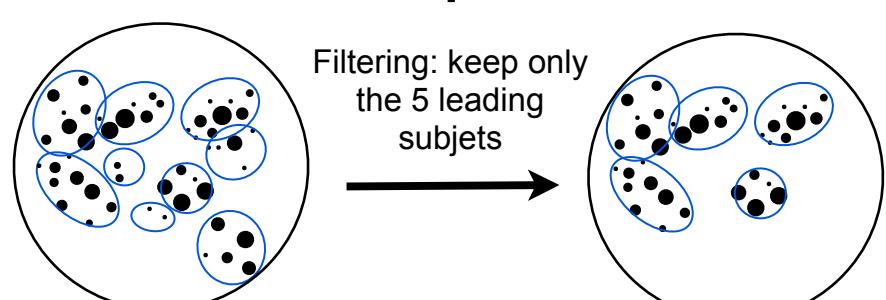
Hadronic Top Reconstruction

HEPTopTagger reconstructs 3-prong jet-substructure where
 $m_{123} \simeq 172 \pm 40 \text{ [GeV]}$

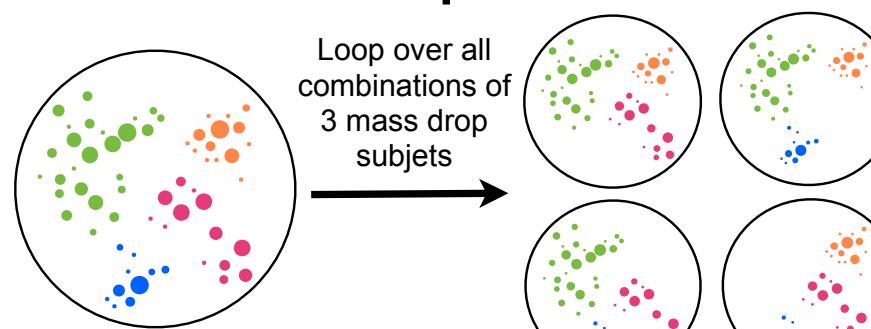
Step 1:



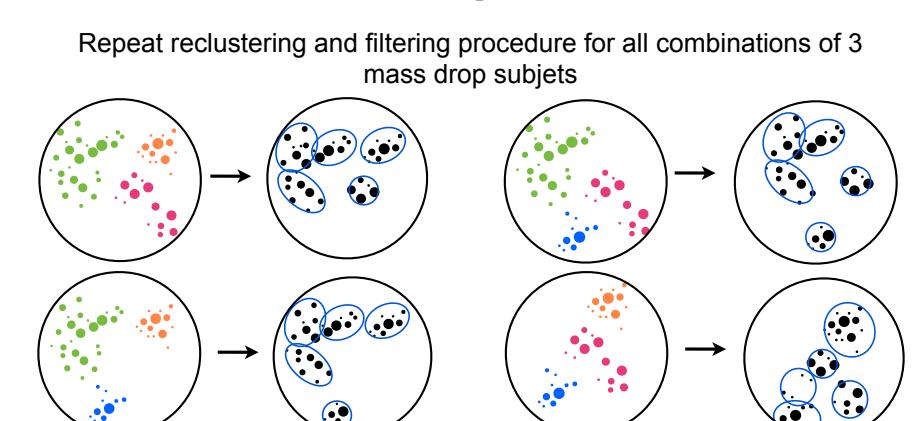
Step 4:



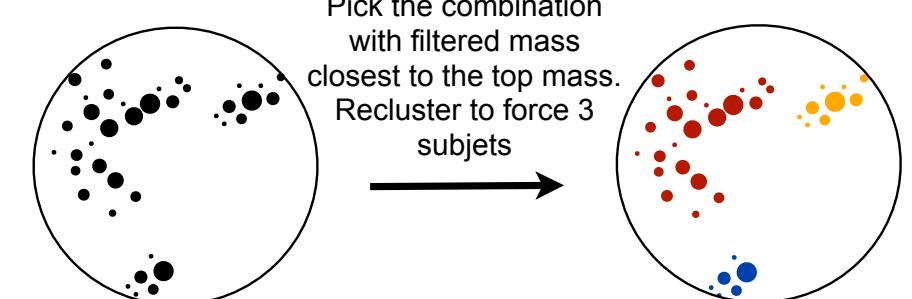
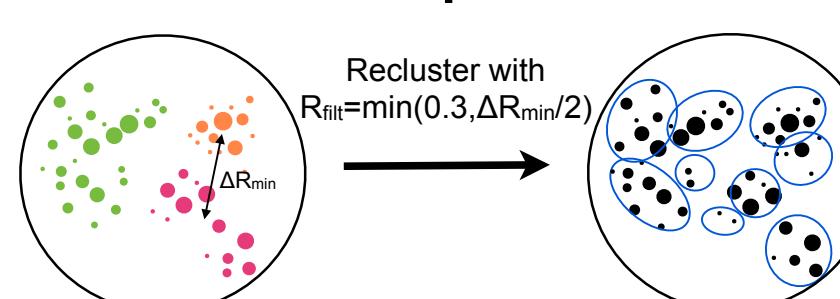
Step 2:



Step 5:



Step 3:



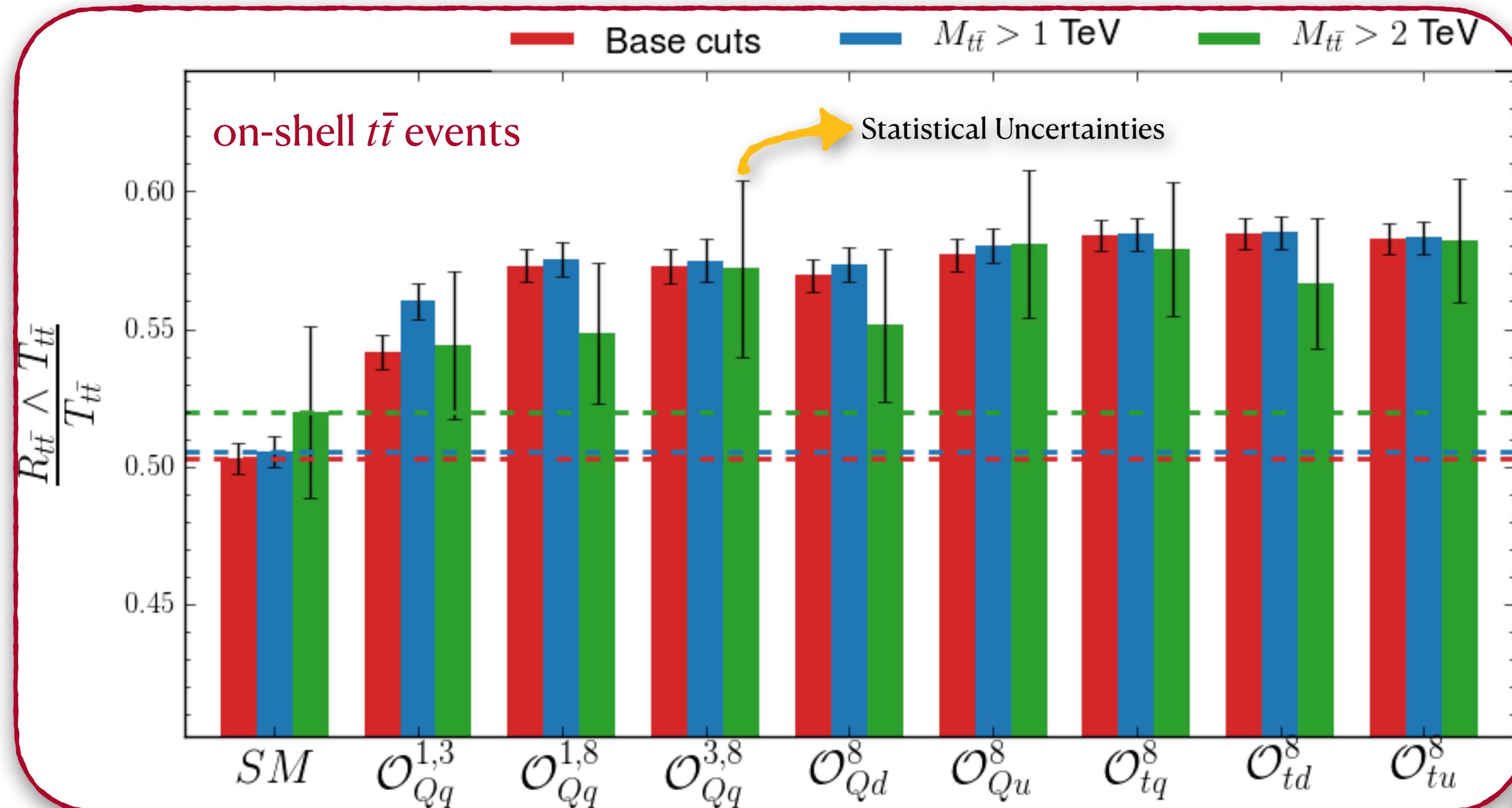
Marzani, Gregory, Spannowsky '19

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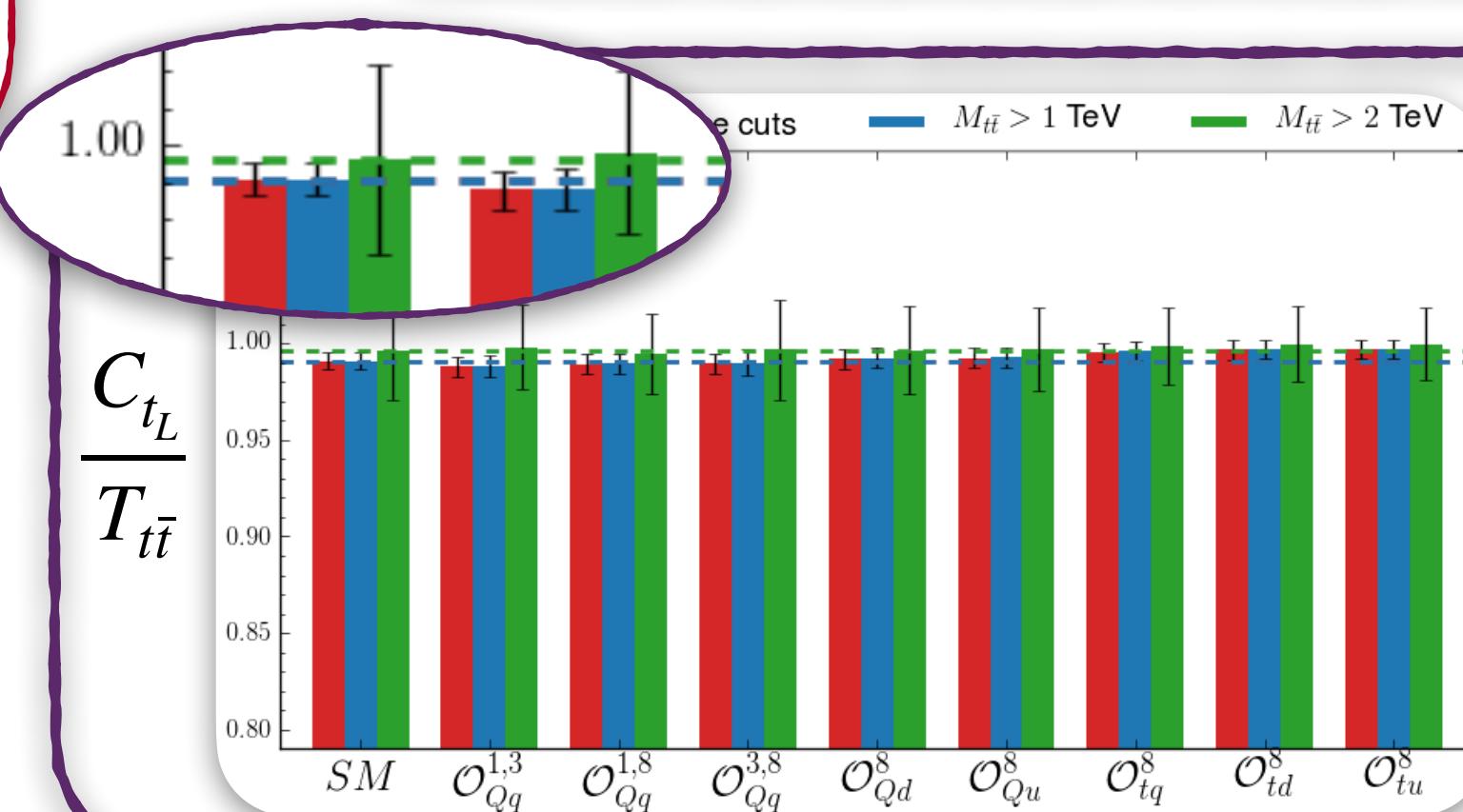
Top tagging efficiency

$R_{t\bar{t}}$:= reconstructed tops $T_{t\bar{t}}$:= Parton level tops



- ❖ Any given tagger is tuned to the SM, which introduces model dependency into the analysis itself.
- ❖ Interference terms with the effective operators are concentrated to the high energy regime; hence depending on the operator, the tagging efficiency deviates from the SM's tagging efficiency.

44% of the full event consists of off-shell leptonic or hadronic top!
This reduces to 11% for $M_{t\bar{t}} > 1$ [TeV]



Leptonic top reconstruction efficiency is ~100%. Hence sensitivity is solely depend on hadronic top reconstruction

$C_{t_L} :=$ Correctly reconstructed leptonic tops, $\Delta R(t_L^{truth}, t_L^{rec}) < 1.5$

LR/RL chiral

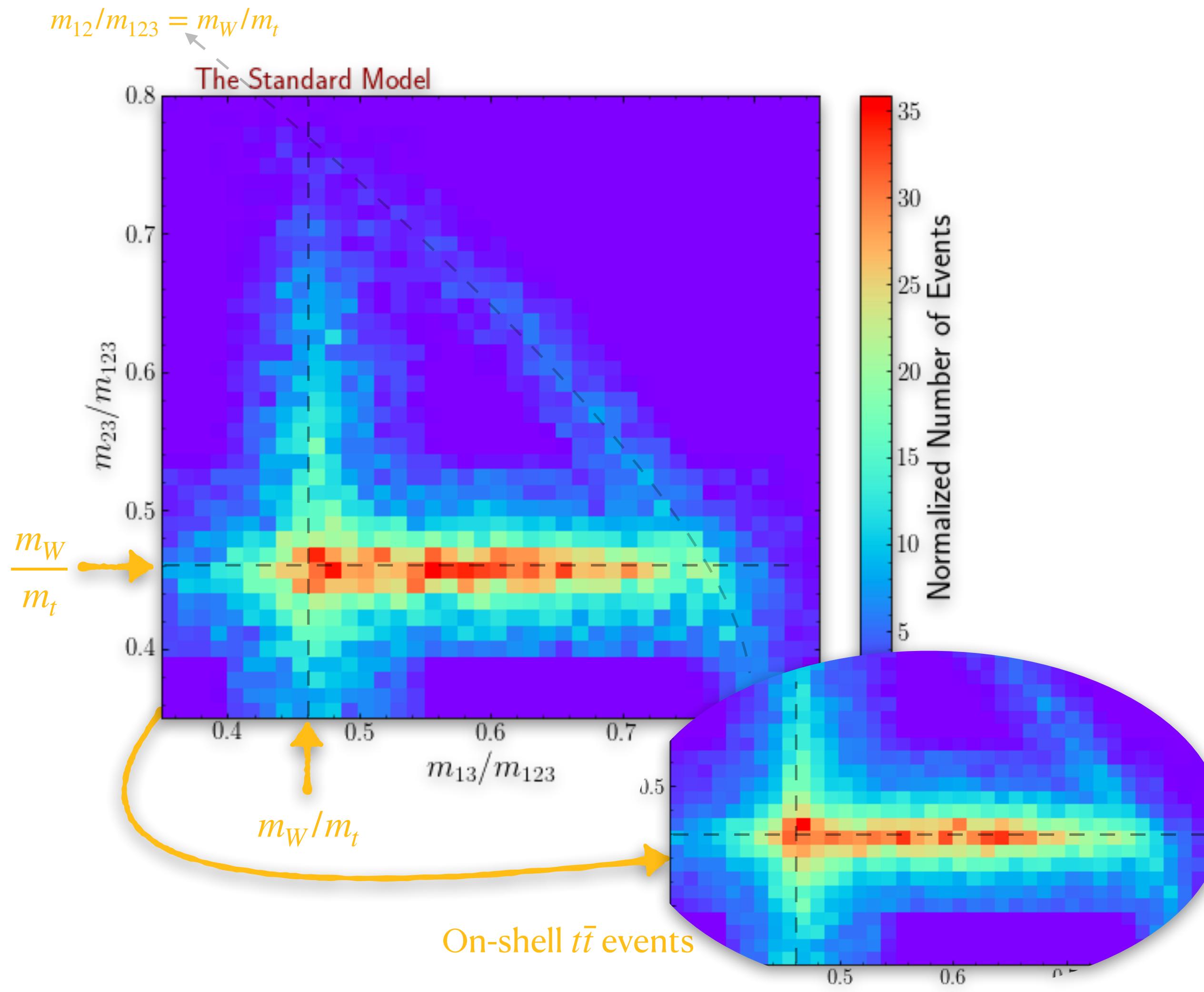
$$\begin{aligned}\mathcal{O}_{tq}^8 &= (\bar{q}_i \gamma^\mu T^A q_i)(\bar{t} \gamma_\mu T^A t) \\ \mathcal{O}_{Qu}^8 &= (\bar{Q} \gamma^\mu T^A Q)(\bar{u}_i \gamma_\mu T^A u_i) \\ \mathcal{O}_{Qd}^8 &= (\bar{Q} \gamma^\mu T^A Q)(\bar{d}_i \gamma_\mu T^A d_i)\end{aligned}$$

LL/RR chiral

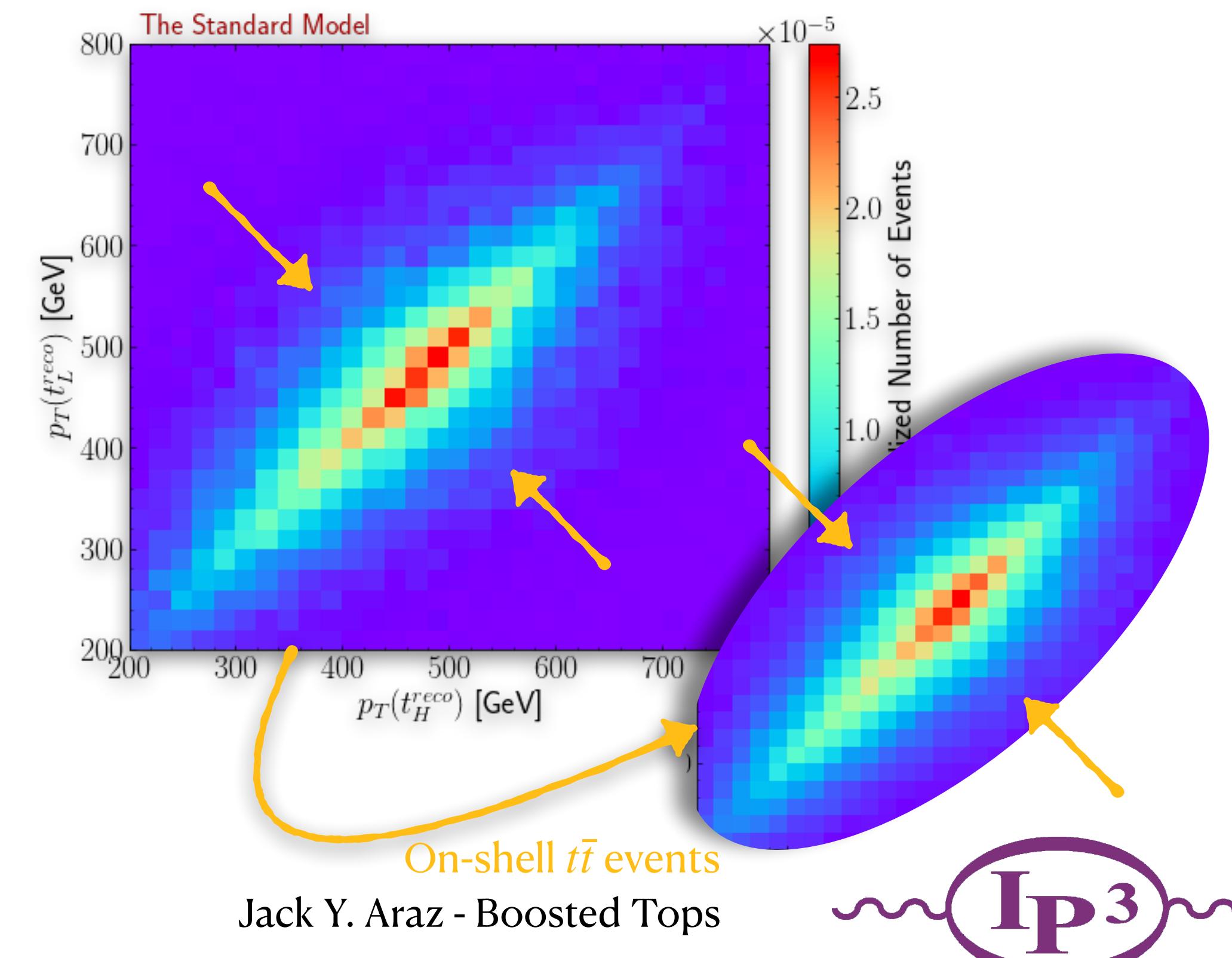
$$\begin{aligned}\mathcal{O}_{tu}^8 &= (\bar{t} \gamma_\mu T^A t)(\bar{u}_i \gamma^\mu T^A u_i) \\ \mathcal{O}_{td}^8 &= (\bar{t} \gamma^\mu T^A t)(\bar{d}_i \gamma_\mu T^A d_i) \\ \mathcal{O}_{Qq}^{3,8} &= (\bar{Q} \gamma_\mu T^A \tau^I Q)(\bar{q}_i \gamma^\mu T^A \tau^I q_i) \\ \mathcal{O}_{Qq}^{1,8} &= (\bar{Q} \gamma_\mu T^A Q)(\bar{q}_i \gamma^\mu T^A q_i) \\ \mathcal{O}_{Qq}^{1,3} &= (\bar{Q} \gamma_\mu \tau^I Q)(\bar{q}_i \gamma^\mu \tau^I q_i)\end{aligned}$$

Gauthier's talk

Tagging full/on-shell $t\bar{t}$ events



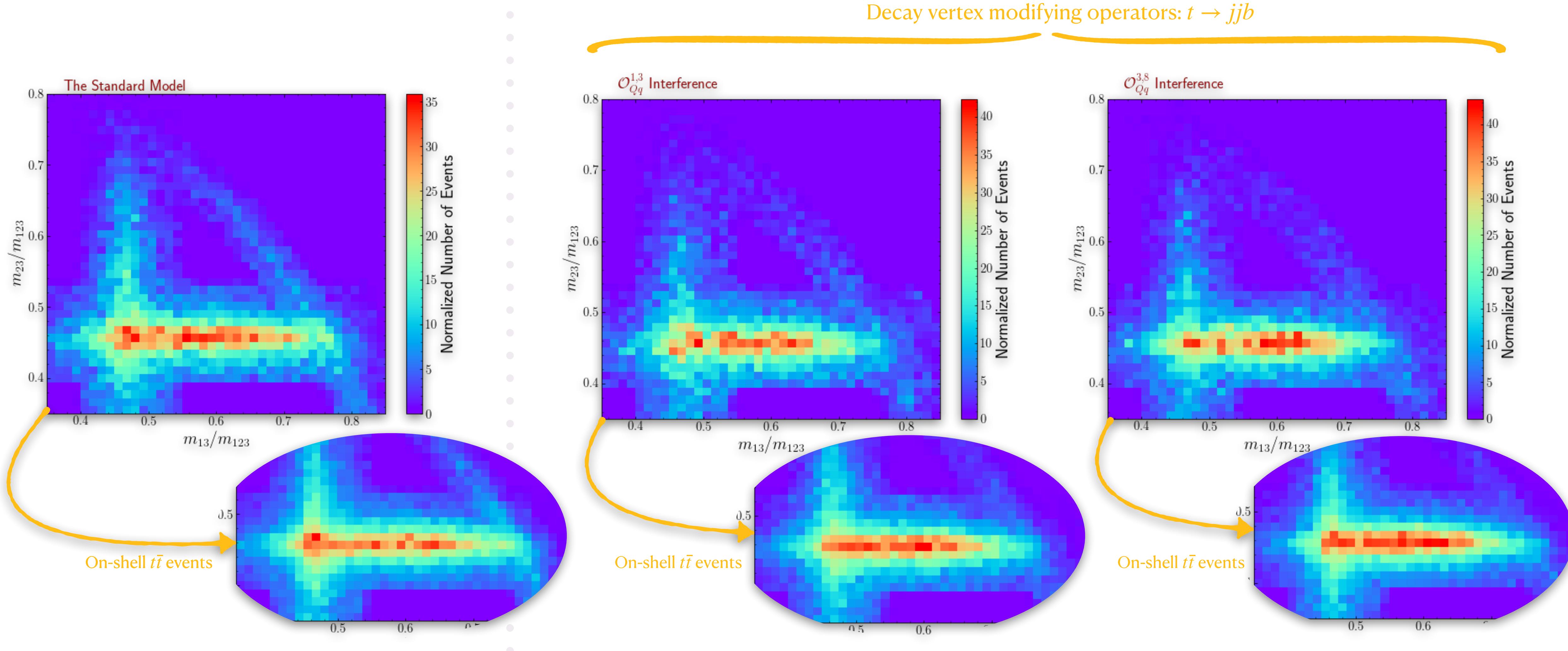
HEPTopTagger is looking for the resonance signature of W and top. Hence, off-shell events only dilute the tagged events, which can be seen from the Dalitz plot.



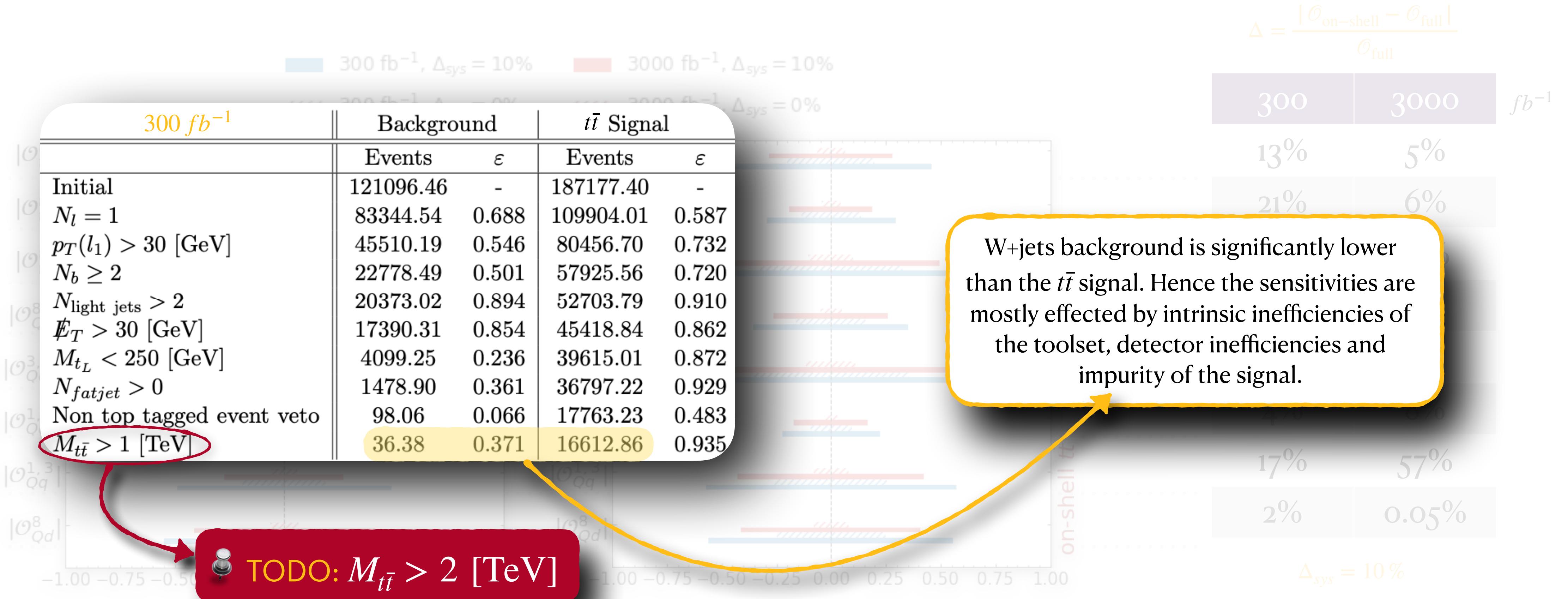
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Tagging full/on-shell $t\bar{t}$ events



Effective Operator Sensitivities



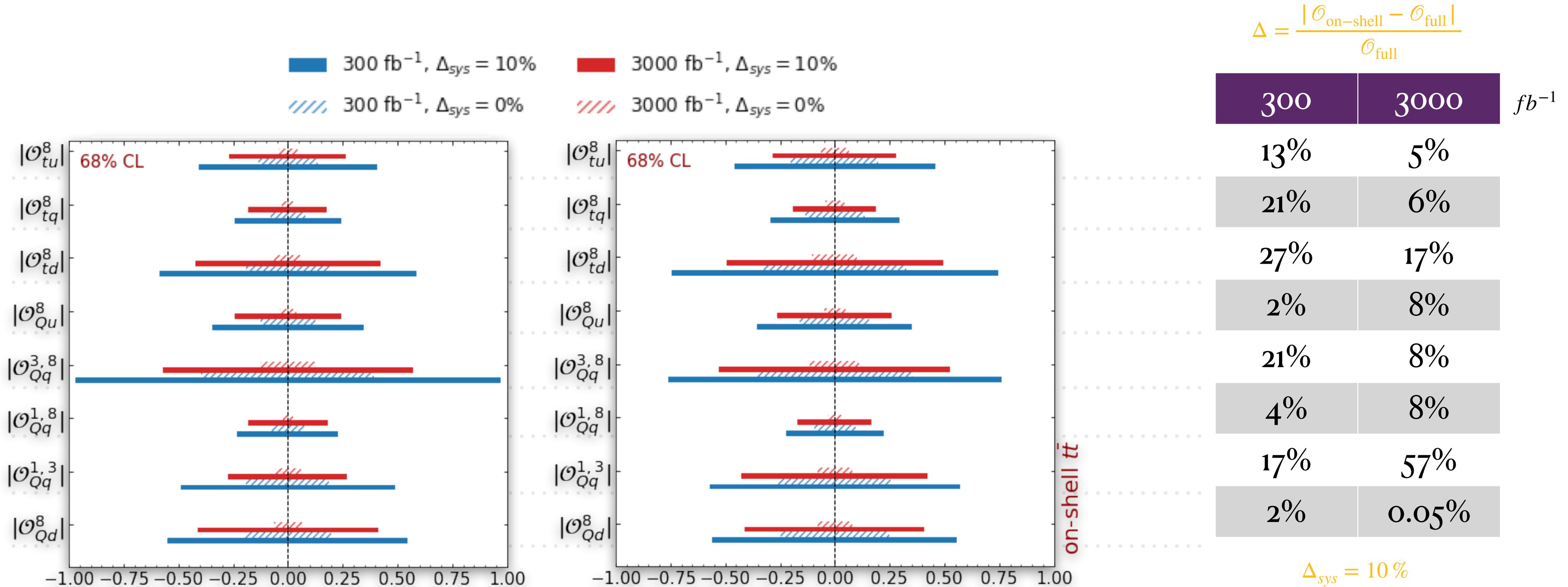
Observables used in sensitivity calculation:

$$\{ H_T, M_{t\bar{t}}, p_T(j_1^{\text{fat}}), p_T(j_1), p_T(l_1), p_T(t_H^{\text{reco}}), p_T(t_L^{\text{reco}}) \}$$

$$\chi^2 = \frac{\mathcal{O}^{\text{exp}} - \mathcal{O}^{\text{obs}}}{\sqrt{\mathcal{O}^{\text{exp}} + (\mathcal{O}^{\text{exp}} \Delta_{\text{sys}})^2}}$$

$\mathcal{O}^{\text{obs}} :=$ SM signal + Background
 $\mathcal{O}^{\text{exp}} :=$ SM signal + EFT interference

Effective Operator Sensitivities



Observables used in sensitivity calculation:

$$\{ H_T, M_{t\bar{t}}, p_T(j_1^{\text{fat}}), p_T(j_1), p_T(l_1), p_T(t_H^{\text{reco}}), p_T(t_L^{\text{reco}}) \}$$

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$\mathcal{O}^{\text{obs}} := \text{SM signal + Background}$

$\mathcal{O}^{\text{exp}} := \text{SM signal + EFT interference}$

Conclusion

- Boosted phase-spaces are perfect laboratory for constraining effective operators.
 - Tagging algorithms are tuned to the SM; hence they are introducing certain biases to the calculation which needs to be taken into account.
 - Off-shell top has significant contribution to the interference terms which again needs to be taken into account. This can be avoided by going higher energies where tagging algorithms are more efficient and underlying event has less off-shell contribution.
- 💡 **TODO:** Effect of detector inefficiencies on operator sensitivities.