Boosted Tops.

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Outline

> **Introduction**
- Motivation
- Why tops? Why boosted?

> **Top Tagging**
- How does it work and why do we need it?
- HEPTopTagger

> **Current Status & Direction**

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Motivation

- No new physics yet (yes, this is a motivation!)
- Very soon we will be drowning in data from LHC!
- Q : What can we learn from this data?
- Q : How to build observables to hunt down new physics? Differential observables, boosted signatures etc.
- SM is only valid upto $\mathcal{O}(\mathrm{TeV})$ scale. More comprehensive model needed to supersede the SM beyond TeV.
- One can expand the effective Lagrangian via higher order terms since they are decoupled at lower energies.

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \mathcal{L}_{\rm eff} = \mathcal{L}_{\rm SM} + \frac{1}{\Lambda}\mathcal{L}_1 + \frac{1}{\Lambda^2}\mathcal{L}_2 + O(\Lambda^{-4}) + h.c. \quad , \quad \mathcal{L}_n = \sum_i C_i O_i$$

Introduction: Why top? Why boosted?

Top Quarks

- Due to their large coupling to the Higgs boson and its weak scale mass, top quark is a major laboratory to understand the nature of EWSB.
- Important production modes: $\underline{\mathbf{t\bar{t}}}$, $t\bar{t}V$, $t\bar{t}H$, single top+jets
- If the new physics lies at a large energy scale, its indirect effects can be parametrized by higher-dimensional operators.

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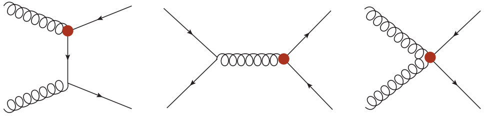
$$O_{tG} = y_t g_s(\bar{t}_L \sigma^{\mu\nu} T_a t_R)\tilde{\phi} G^a_{\mu\nu}$$

O_{tG} :



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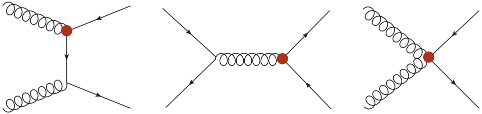
$$O_G = f_{abc} G^{a\nu}_{\mu} G^{b\rho}_{\nu} G^{c\mu}_{\rho} \quad , \quad O_{\phi G} = \frac{1}{2}(\phi^\dagger \phi) G^a_{\mu\nu} G^{a\mu\nu}$$

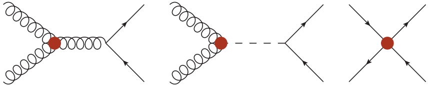
$$O^{33}_{Dd} = (\bar{t}_L D_\mu b_R) D^\mu \phi \quad , \quad O^{33}_{\bar{D}d} = (D_\mu \bar{t}_L b_R) D^\mu \phi$$

$$O_{tW} = (\bar{q}\sigma^{\mu\nu}\tau^I t)\tilde{\phi} W^I_{\mu\nu} \quad , \quad O_{4q} \text{ (7 operators)}$$

O_{tG} :

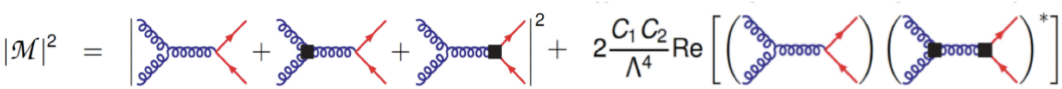


O_G, $O_{\phi G}$, O_{4q} :



How does EFT work?

- **SMEFT Amplitude**



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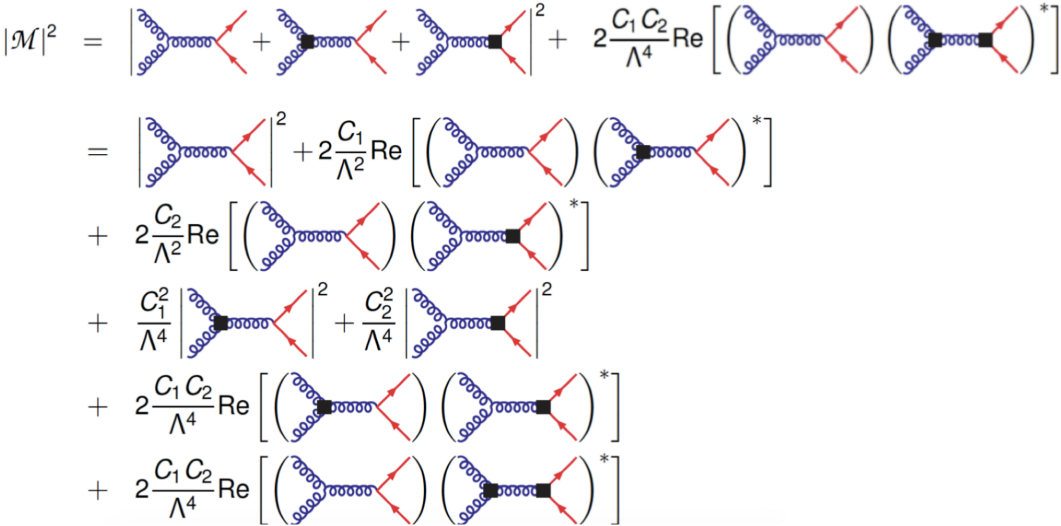

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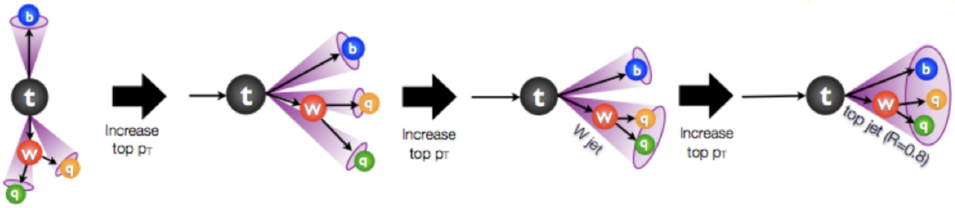
Top Tagging

Rule of thumb: $R = \frac{2m_t}{p_T}$



[McLean, 2016]

Why cluster?

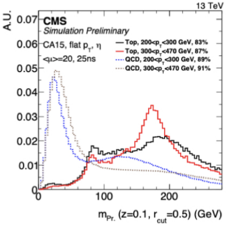
- A typical collision event has a substantial amount of collimated particles
  - Detector can not identify each of them
  - There is not much information in every single particle.

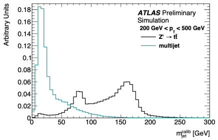
Top Tagging

Substructure tools in the market

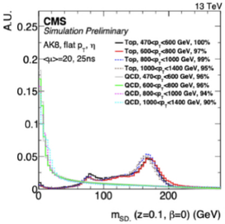
- Mass Grooming & Filtering: Reduces contamination from ISR and pile-up
- Pruning: Rejects soft & large angle constituents during iterative reclustering.
- Trimming: Recluster while keeping constituents with $p_{T,i}/p_T = X$.
- Soft Drop: Removes wide angle soft radiation
- Hopkins/CMS, template tagger, BDRS (mostly for Higgs)...

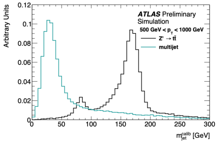
Pruning





Softdrop





Trimming

[CMS-JME-15-002] [ATL-PHYS-PUB-2015-053]

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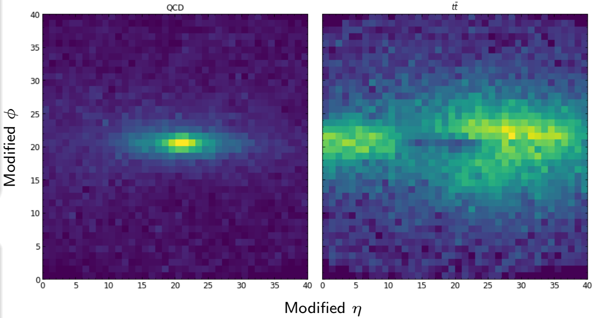
Fun but less analytic

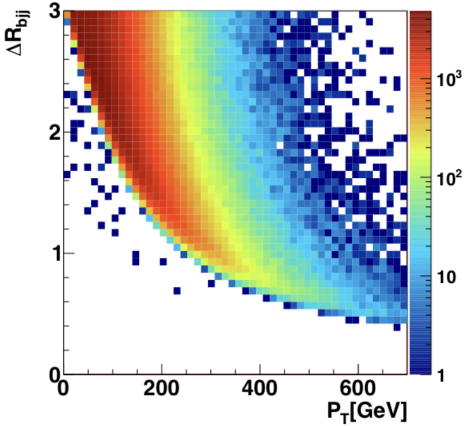
- Event and shower deconstruction.
- Deep Neural Networks



[JYA, Spannowsky; *ongoing*]

HEPTopTagger

FatJet (C/A with R=1.5 (1.8) and $p_T^{min} = 200\ (150)$ GeV)



[Plehn; 2014]

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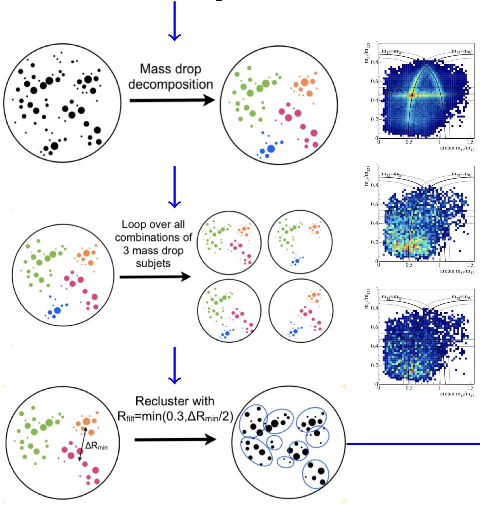
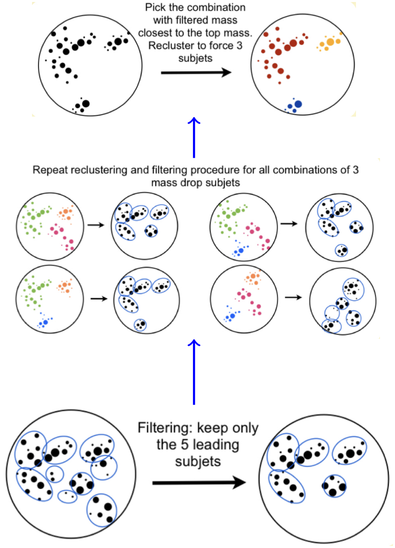
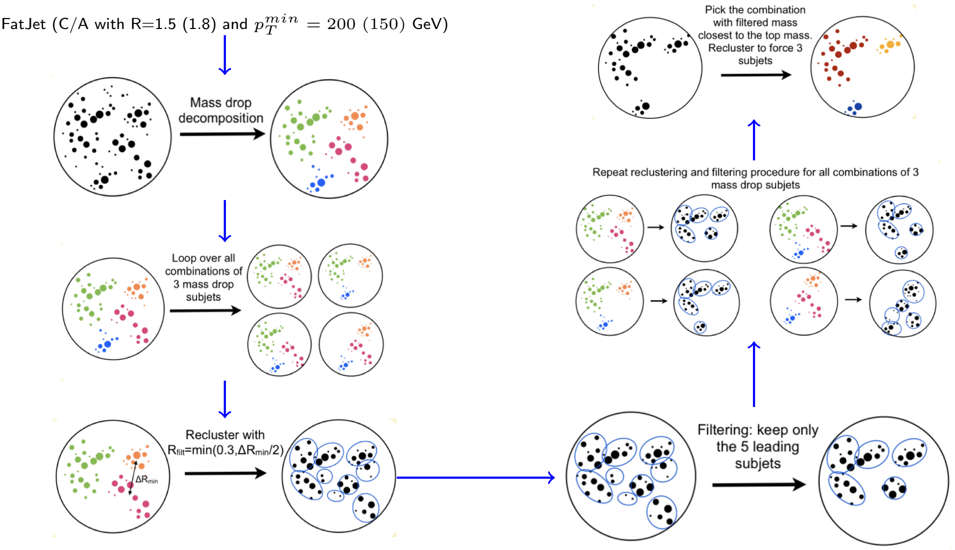


[Plehn,Spannowsky, Takeuchi; 2011]



[Marzani,Soyez,Spannowsky; 2019]

HEPTopTagger



[Marzani,Soyez,Spannowsky; 2019]

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- Theoretical uncertainties: scale & PDF
- QCD shower model (pythia, herwig etc.)
- Experimental biases
  - Rivet [Buckley, Kar, Nordstorm; 2020]
  - MadAnalysis 5 [JYA, Fuks; *soon*]

Plan for public sorftware

- Multi-Cluster jet analysis with MadAnalysis 5 (complete v1.9)
- HEPTopTagger integration for public use
- Cross validation of both frameworks

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Thanks for your time, keep safe!