Recent results using jet substructure from the LHC

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Prologue

What do we do at the LHC?

1. Search for signatures of new physics

1. Search for signatures of new physics

How?

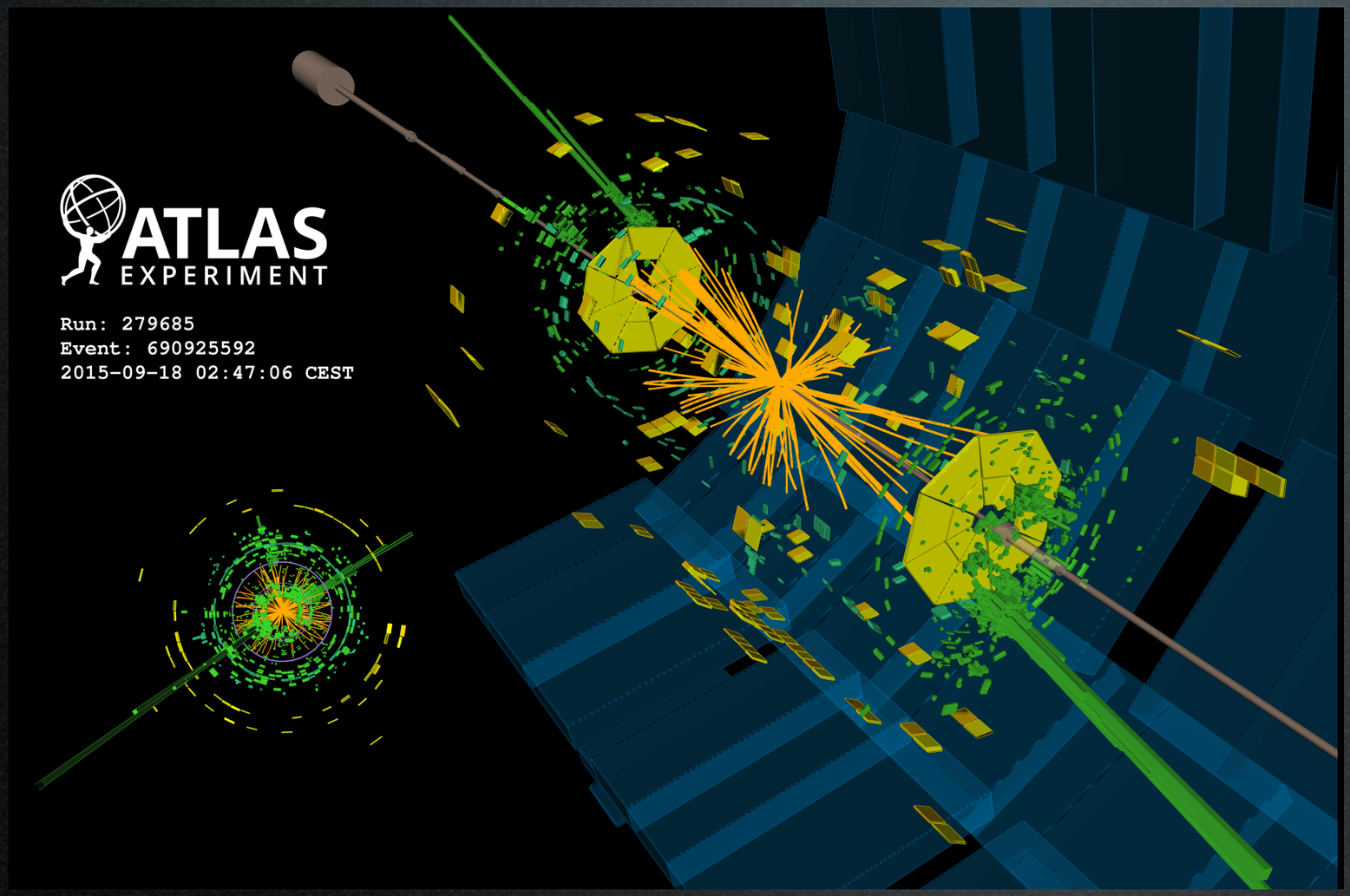
1. Search for signatures of new physics

Bump hunting!

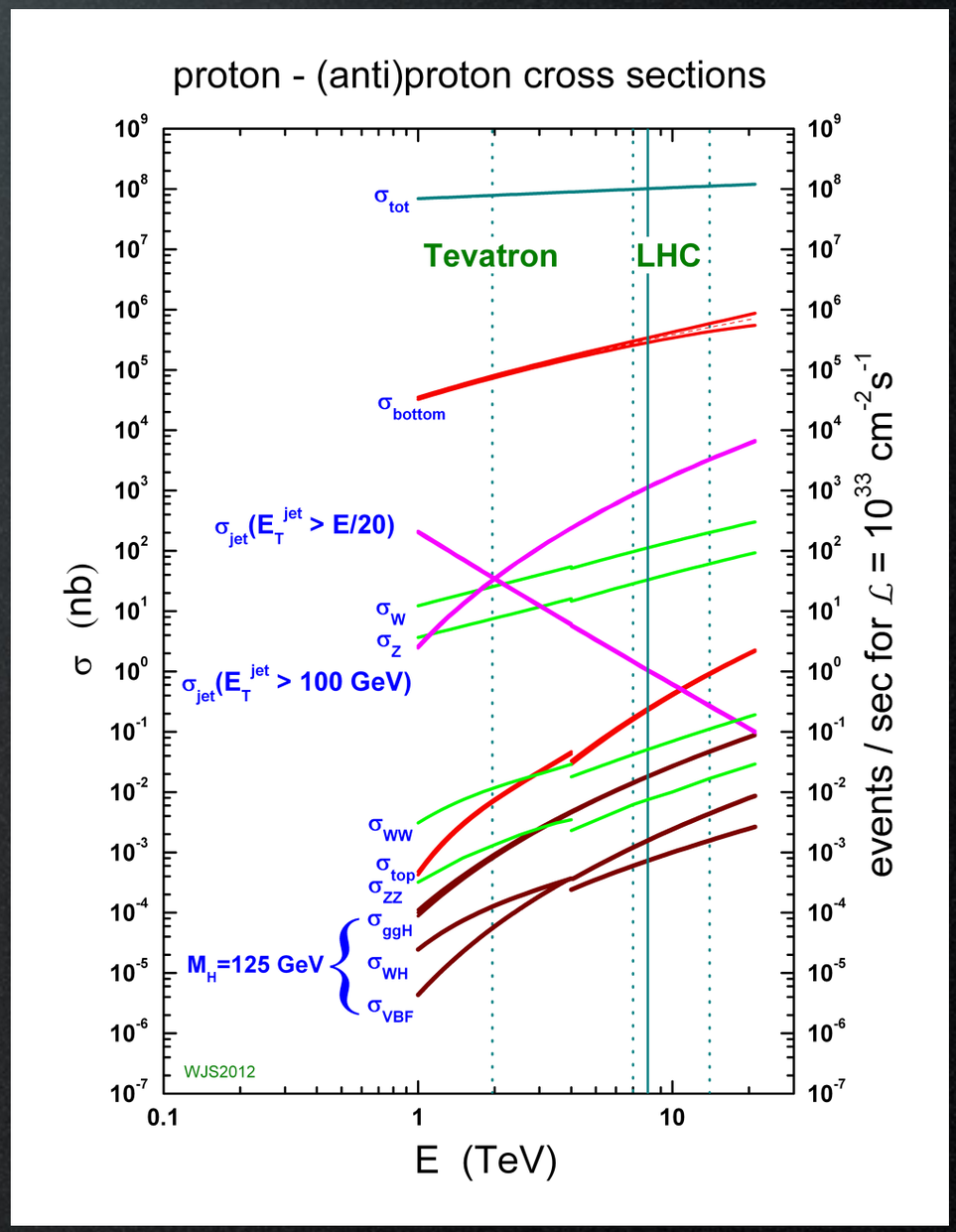
1. Search for signatures of new physics
2. Measure SM processes at a new energy regime


quantum lolcats
demonstrate supersymmetry
ICANHASCHEEZBURGER.COM

Jets



LHC is a
jet factory!

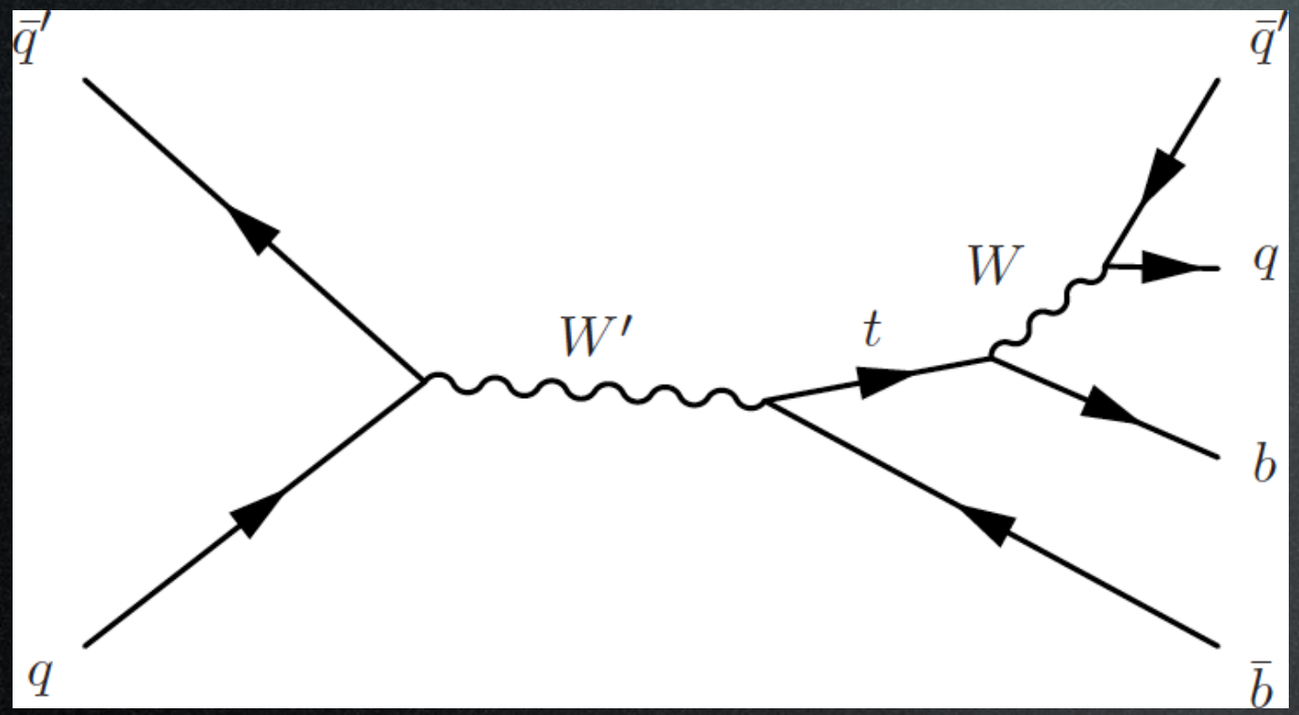


As a signal, test of
QCD predictions

Background for most analyses

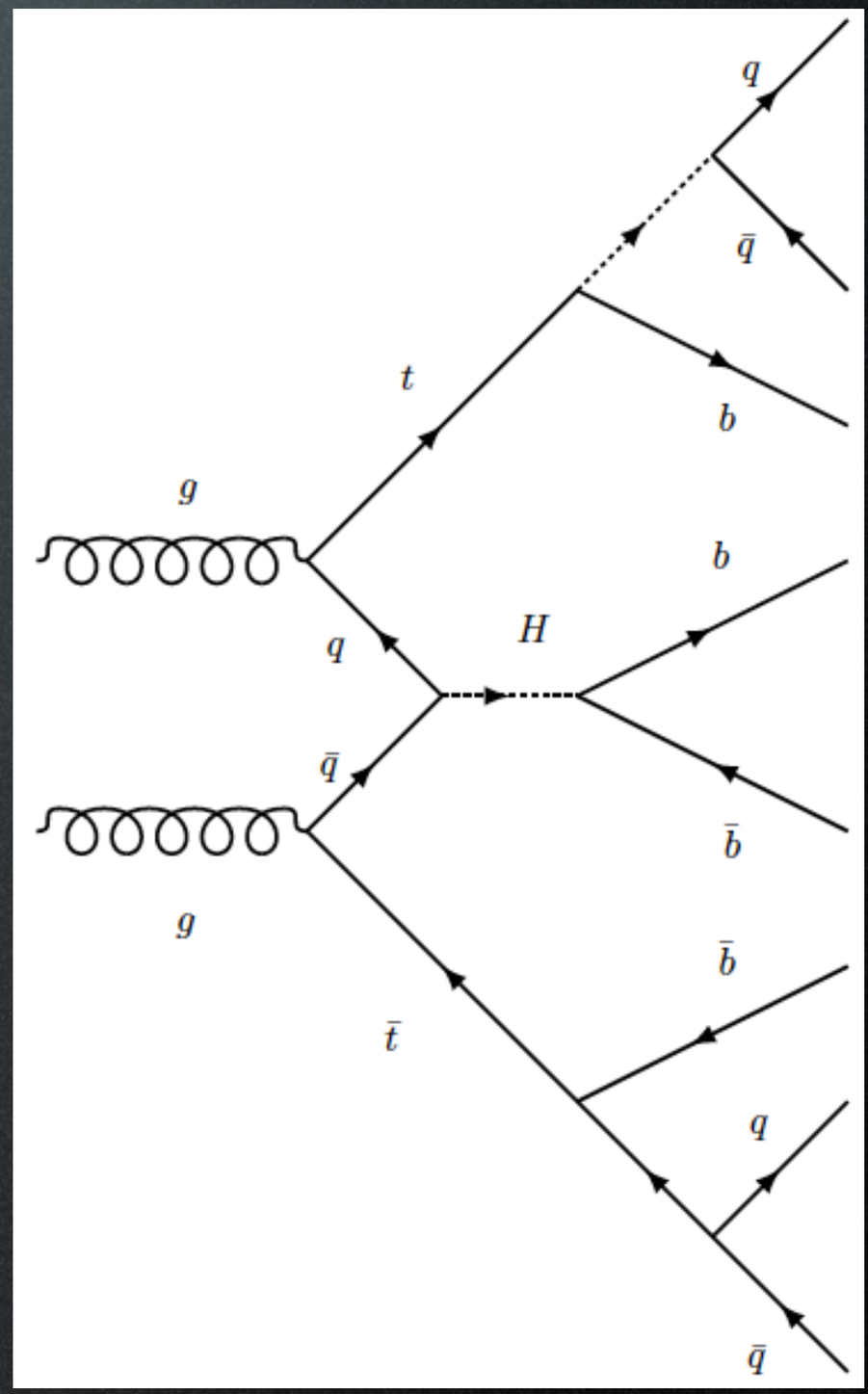
Searches with many jets

W prime (all hadronic)



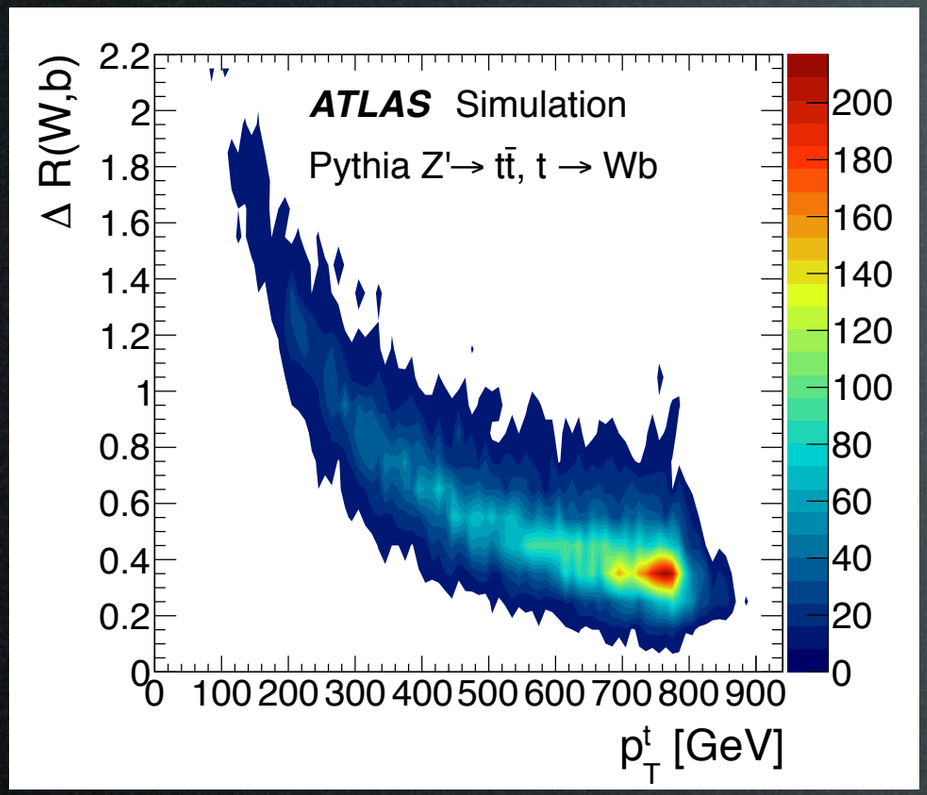
A combinatorial nightmare!

tth(bb)



Way out?

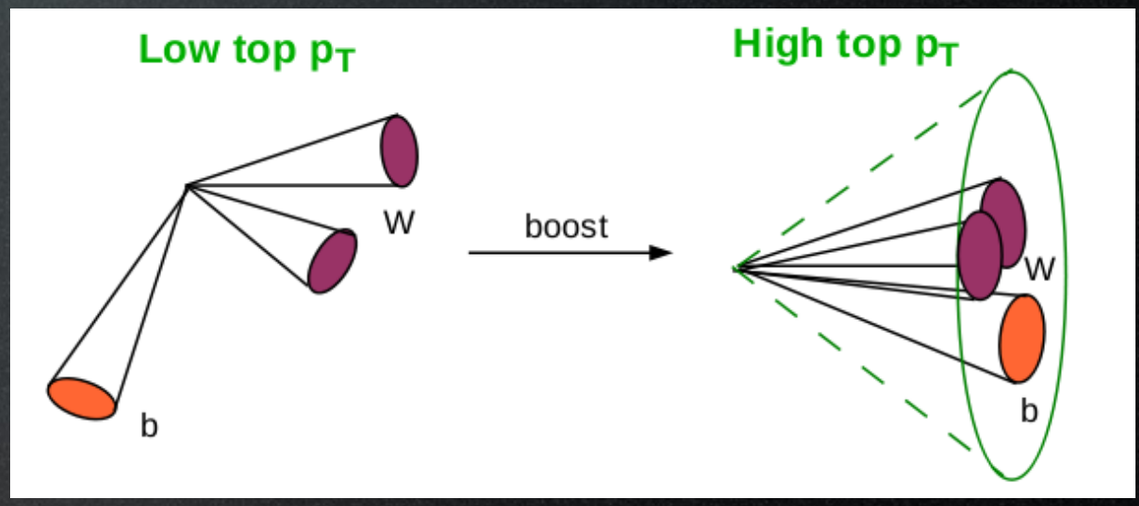
Use large-radius jets to encompass all decay products from a heavy hadronically decaying particle



A large radius jet of $R = 2m/p_T^{\wedge}2$ can contain all decay products

Hadronically decaying top quark, Higgs/ W/Z bosons, new heavy particles ...

Exploit the internal structure of the large radius jet coming from signal to distinguish them from large radius jet coming from background (light quark, gluon, lepton)



Preferred jet algorithms are k_t or CA, as they preserve clustering order

So when you take apart a jet, what does it look like?

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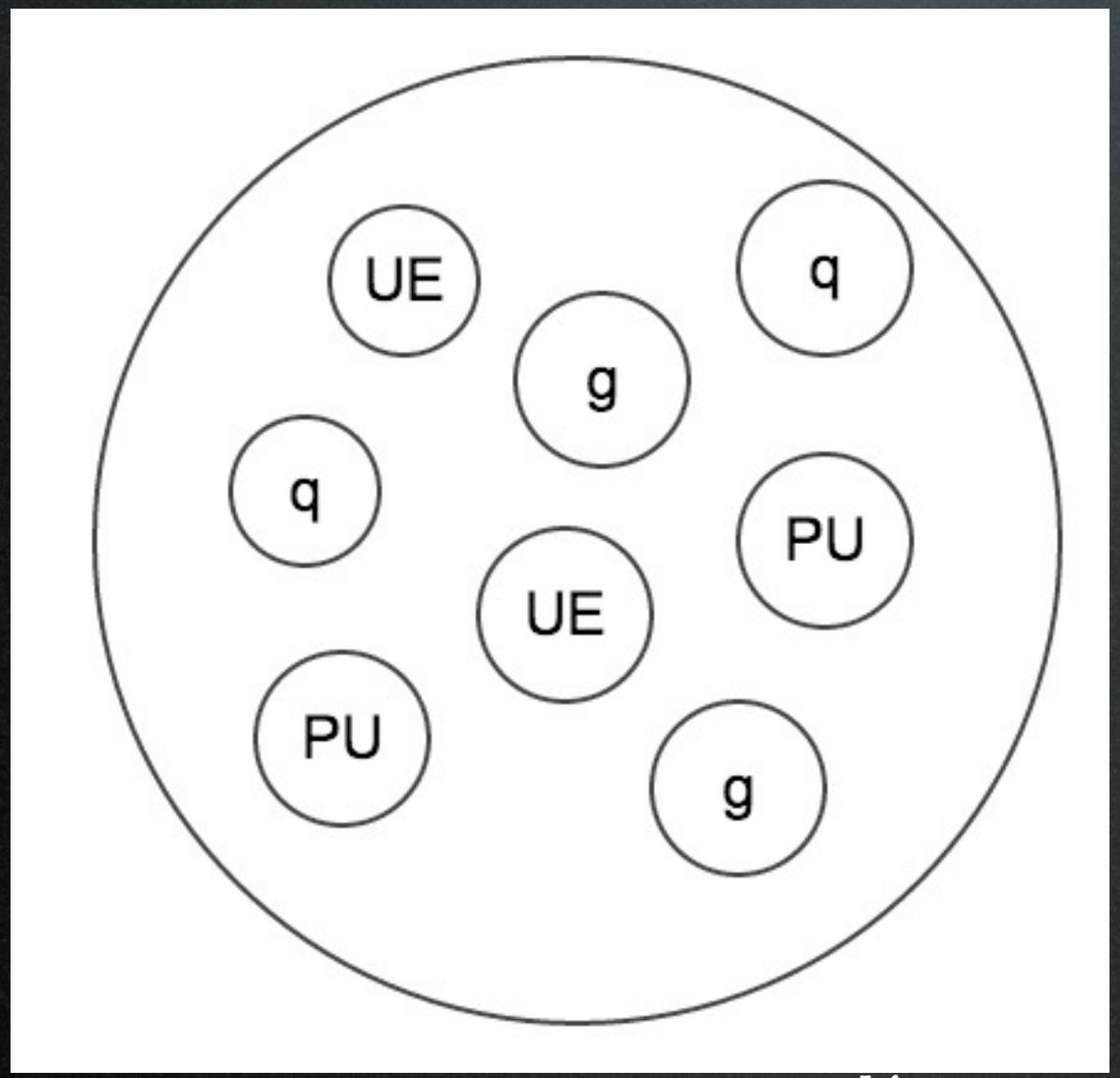


We want to exploit the "substructure" of the large-radius jet to identify original particles

Jets need to be groomed!

- Mass drop filtering
- Pruning
- Trimming
- Soft Drop

Why?

The large-radius jets not only include particles coming from the interesting decays, but also from pileup, underlying event ....

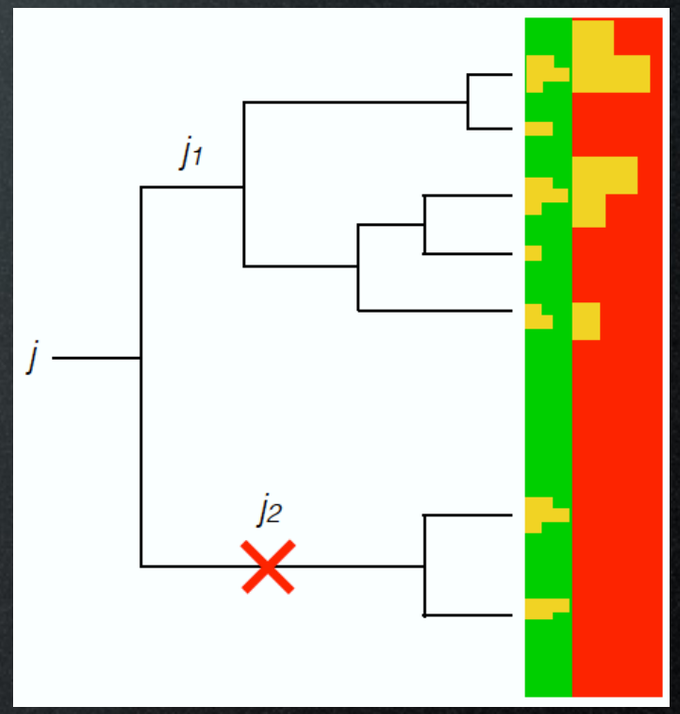
Larkoski, Marzani, Soyez,Thaler, 2014

Soft Drop

Start with a jet j and it is split into last two subjets

If:

$$\frac{min(p_{T1}, p_{T2})}{p_{T1} + p_{T2}} > z_{cut} \left(\frac{\Delta R_{12}}{R_0} \right)^{\beta}$$



Then j is the final soft drop jet.

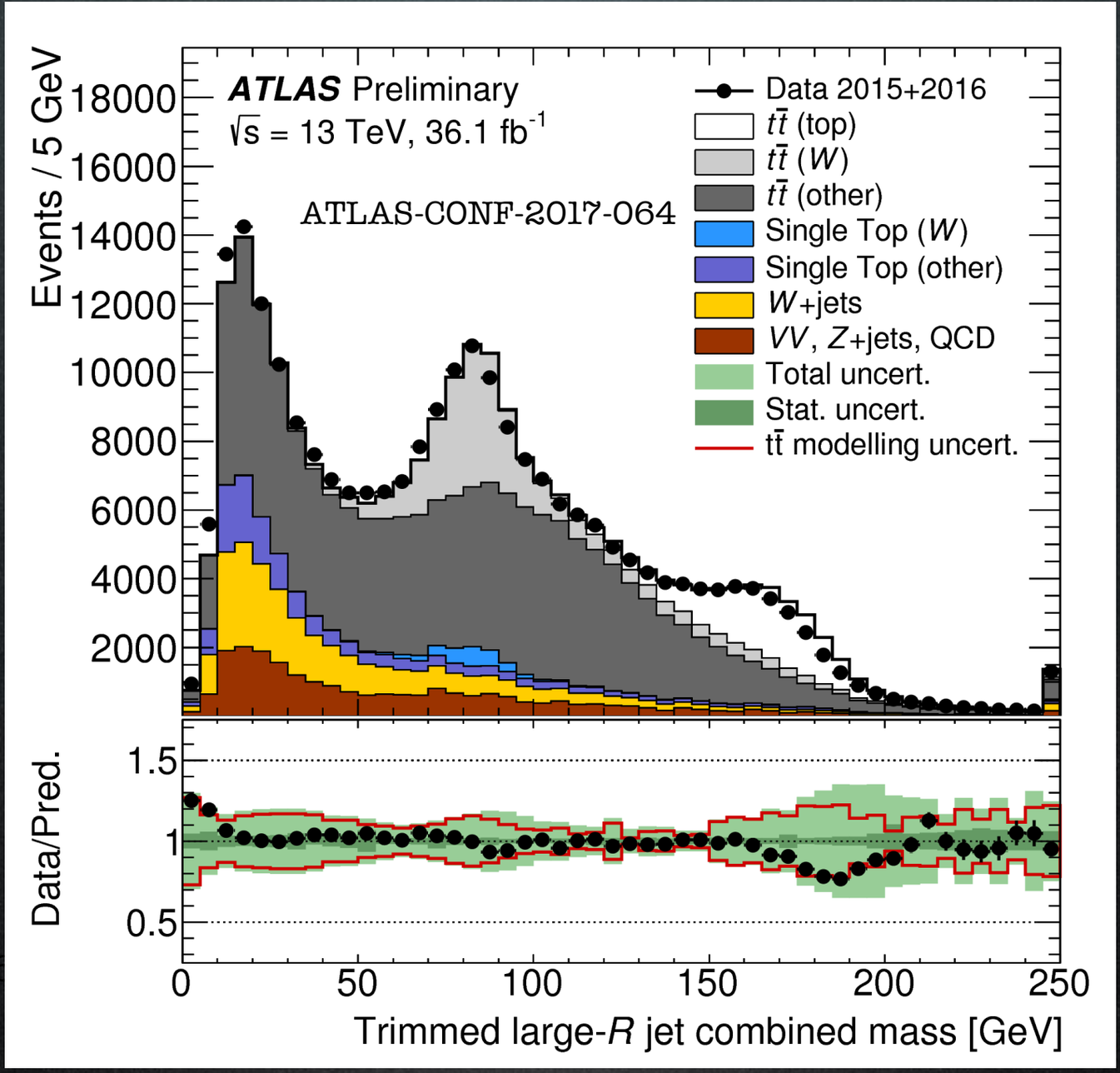
Otherwise the higher p_T subjet is taken as j and iterated ...

Advantage: can be compared directly to analytic calculations

Effect of Gardening?

Effect of Gardening?

W and Top Mass

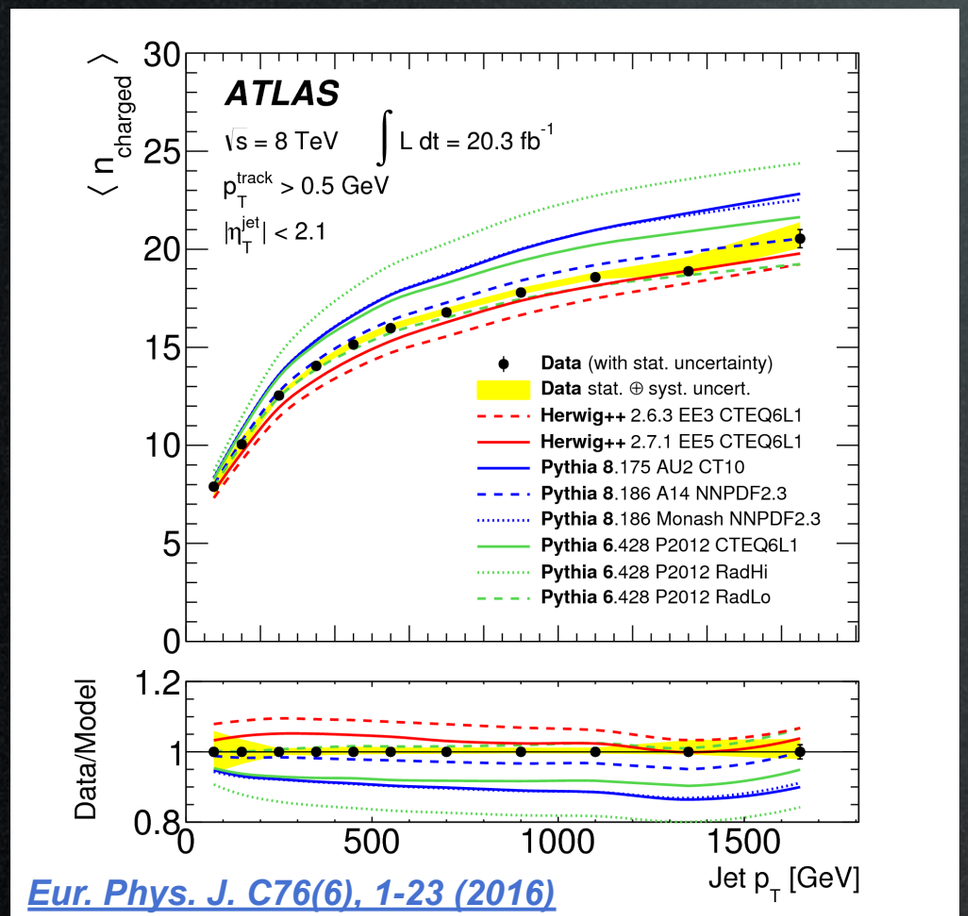


Eur. Phys. J. C 76(3) (2016

Mass peaks clearly visible over background!

A brief detour: measurements

Why Measurement?



Eur. Phys. J. C76(6), 1-23 (2016)

Jet (sub)structure is mostly dependent on Parton Shower models

Non negligible differences from data are observed in MC predictions

(Unfortunately) Grooming to get rid of uncorrelated radiation also throws away the soft part we wish to tune to!

"Your garbage is my treasure"

Attributed to Stefan Prestel

Why Measurement?

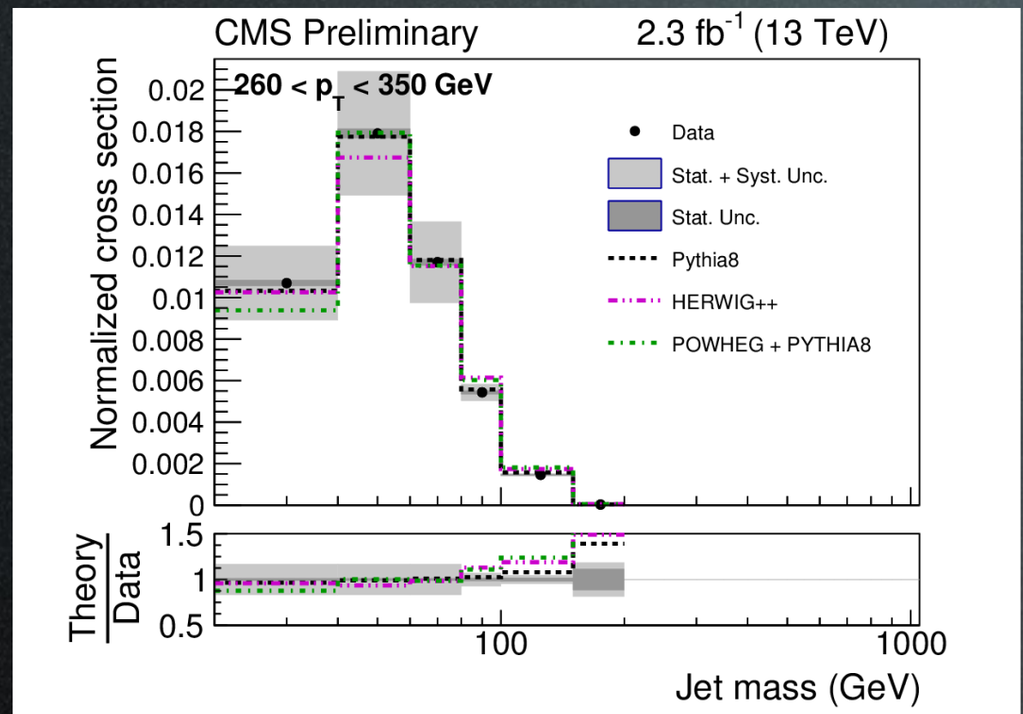
Sensitive to both perturbative and non-perturbative QCD (“precision substructure”)

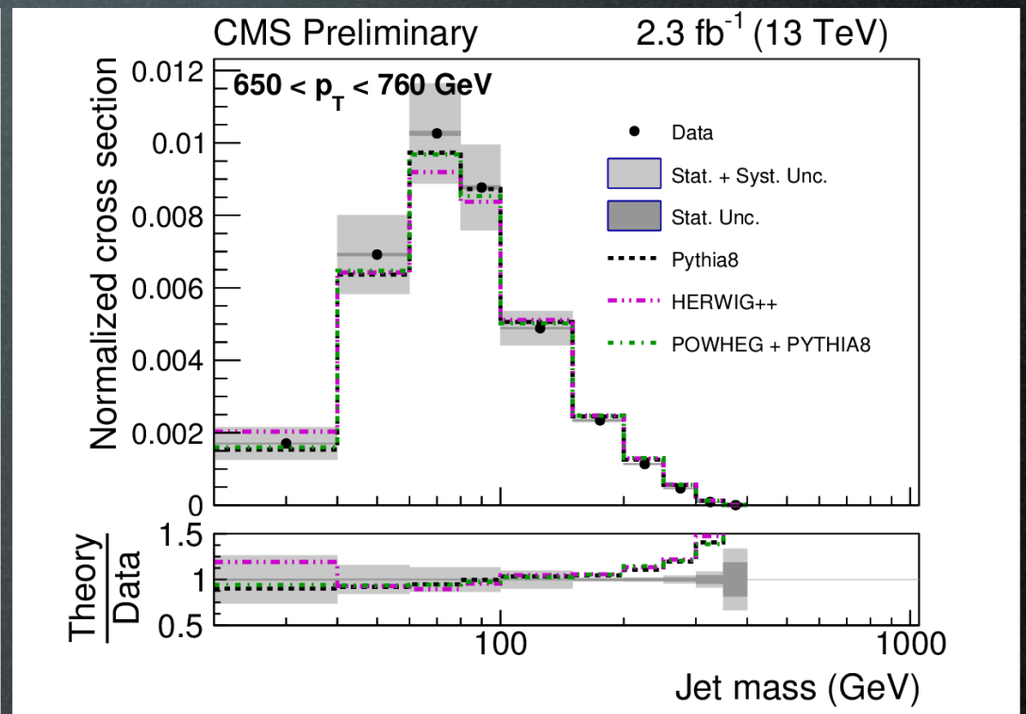
Input to tune/improvement models and analytic calculations

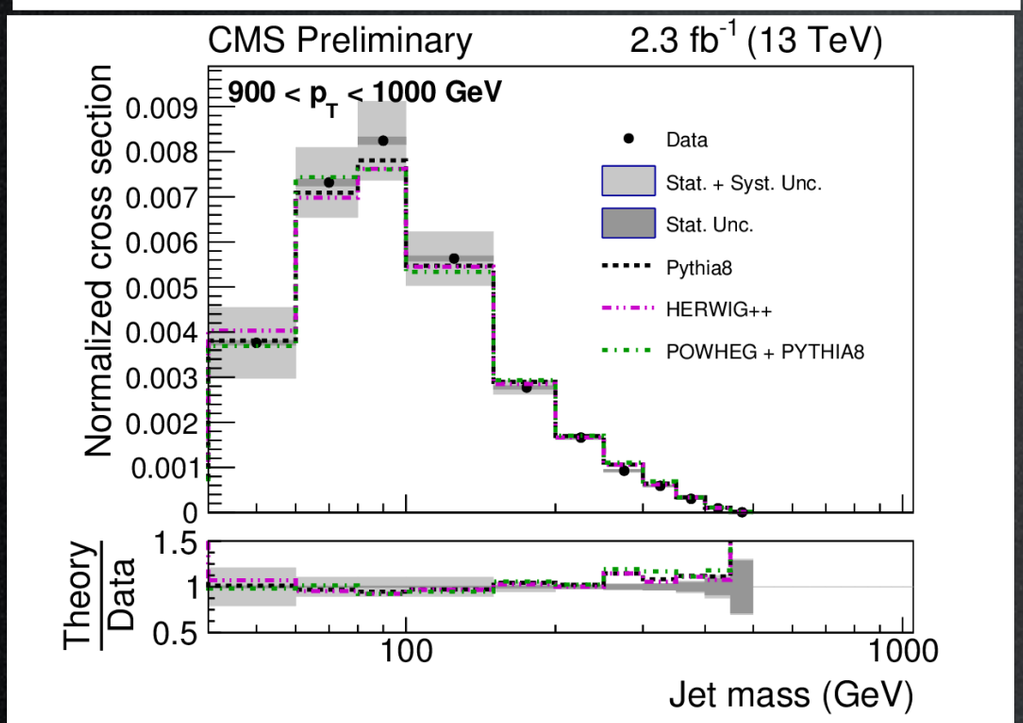
Helps in tagging algorithm development.

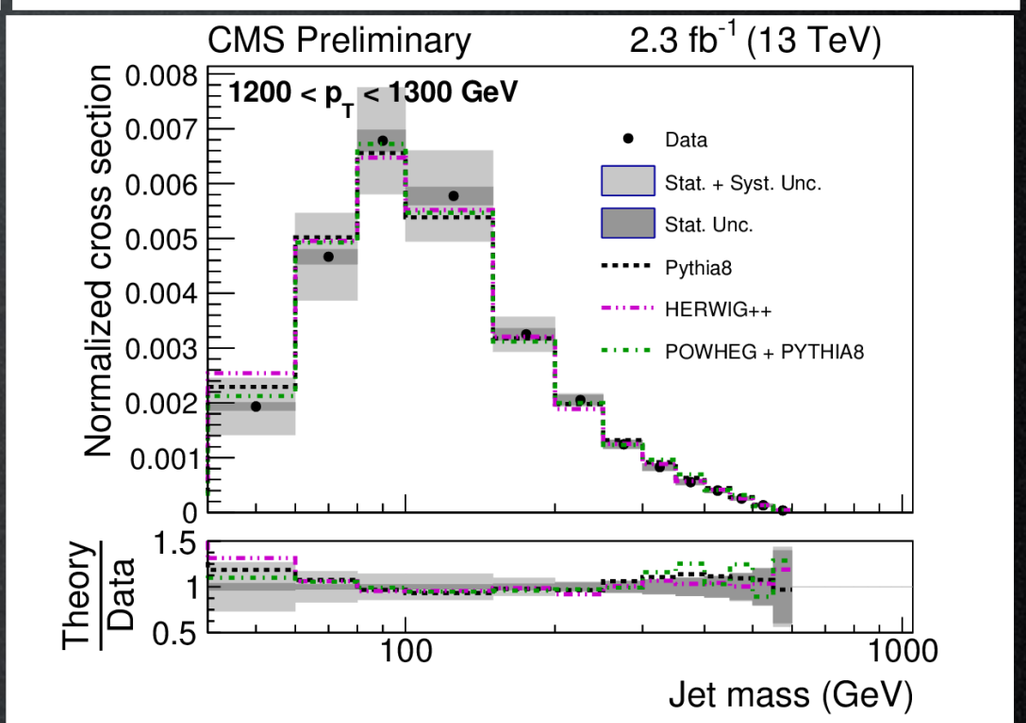
CMS-PAS-SMP-16-010

Ungroomed Jet Mass



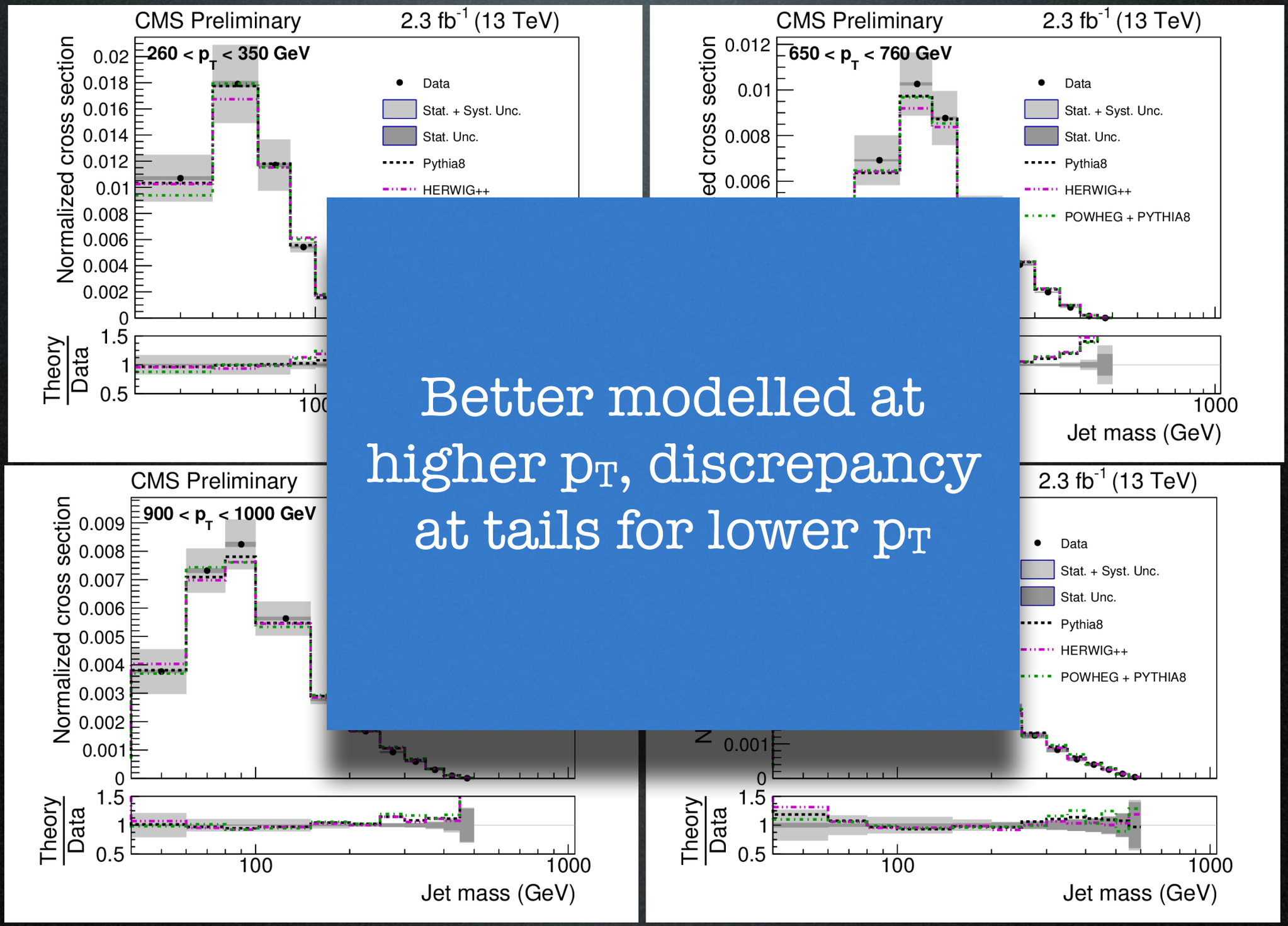






CMS-PAS-SMP-16-010

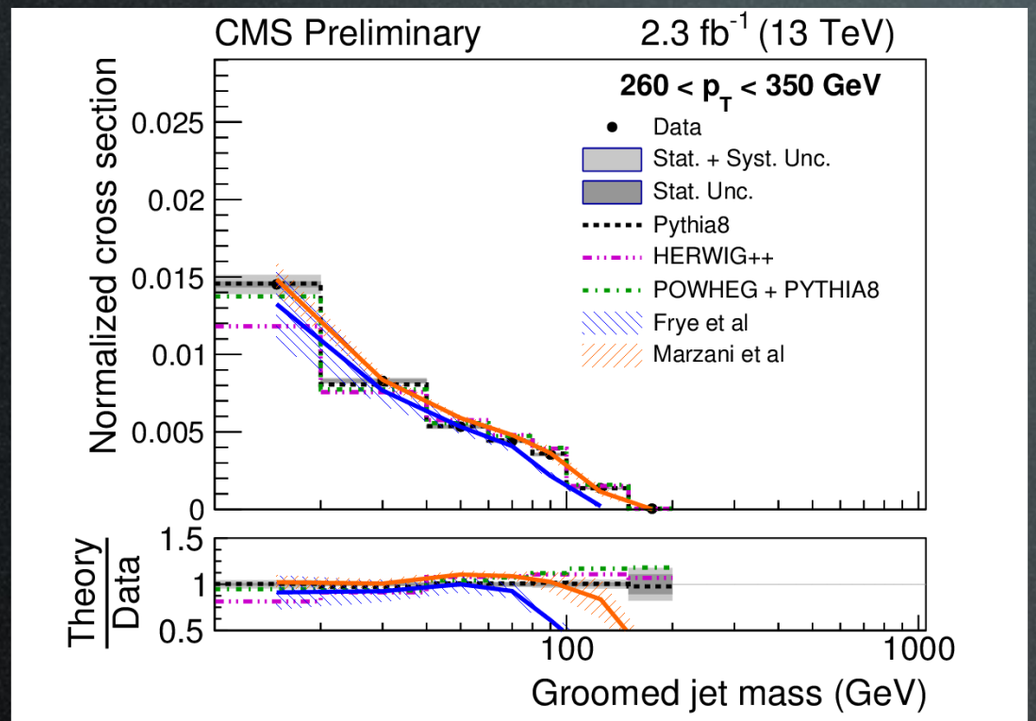
Ungroomed Jet Mass

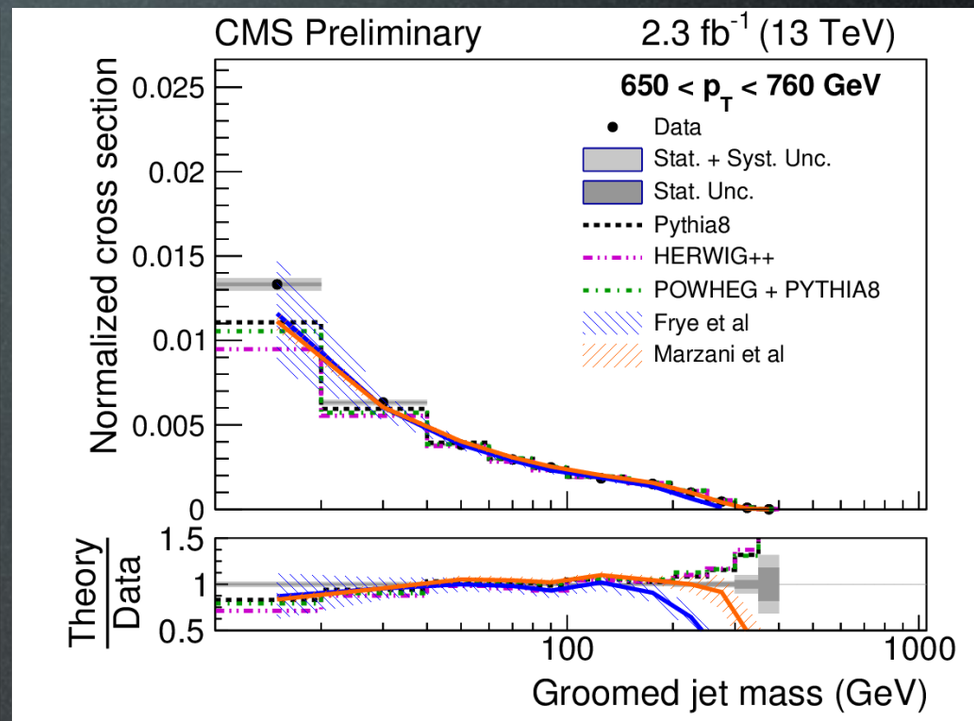


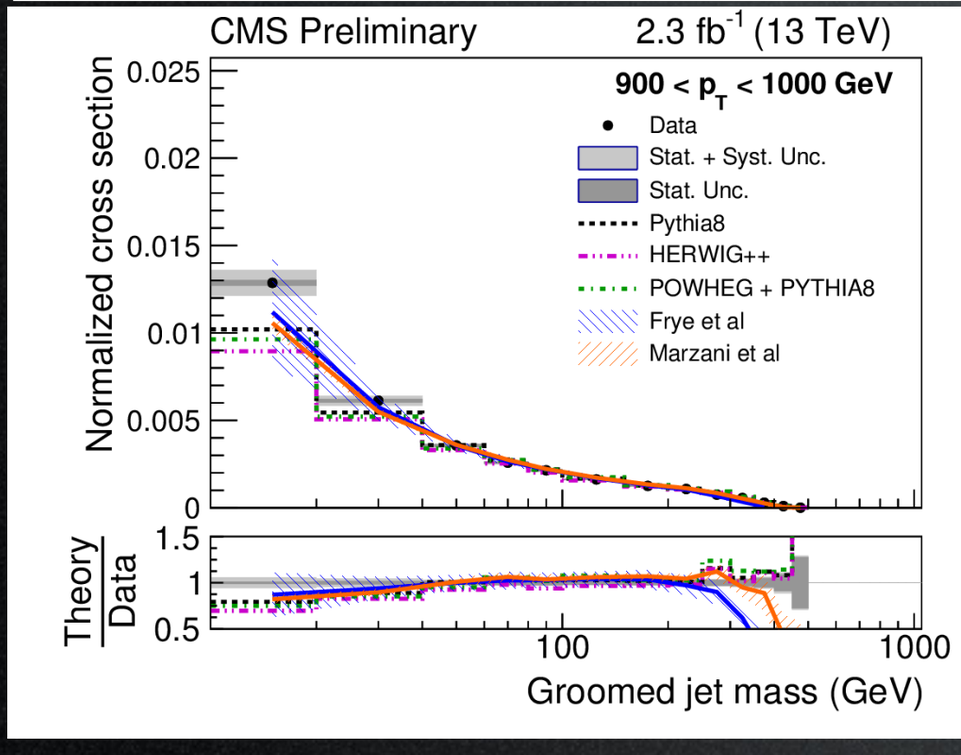
Better modelled at higher p_T, discrepancy at tails for lower p_T

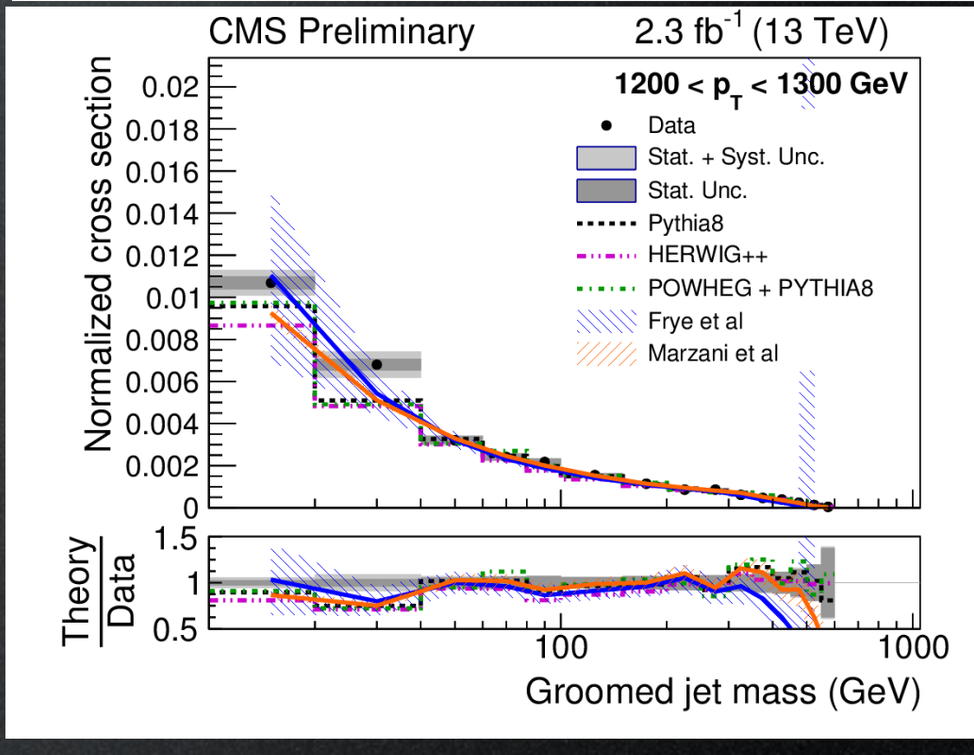
CMS-PAS-SMP-16-010

Soft-dropped Jet Mass



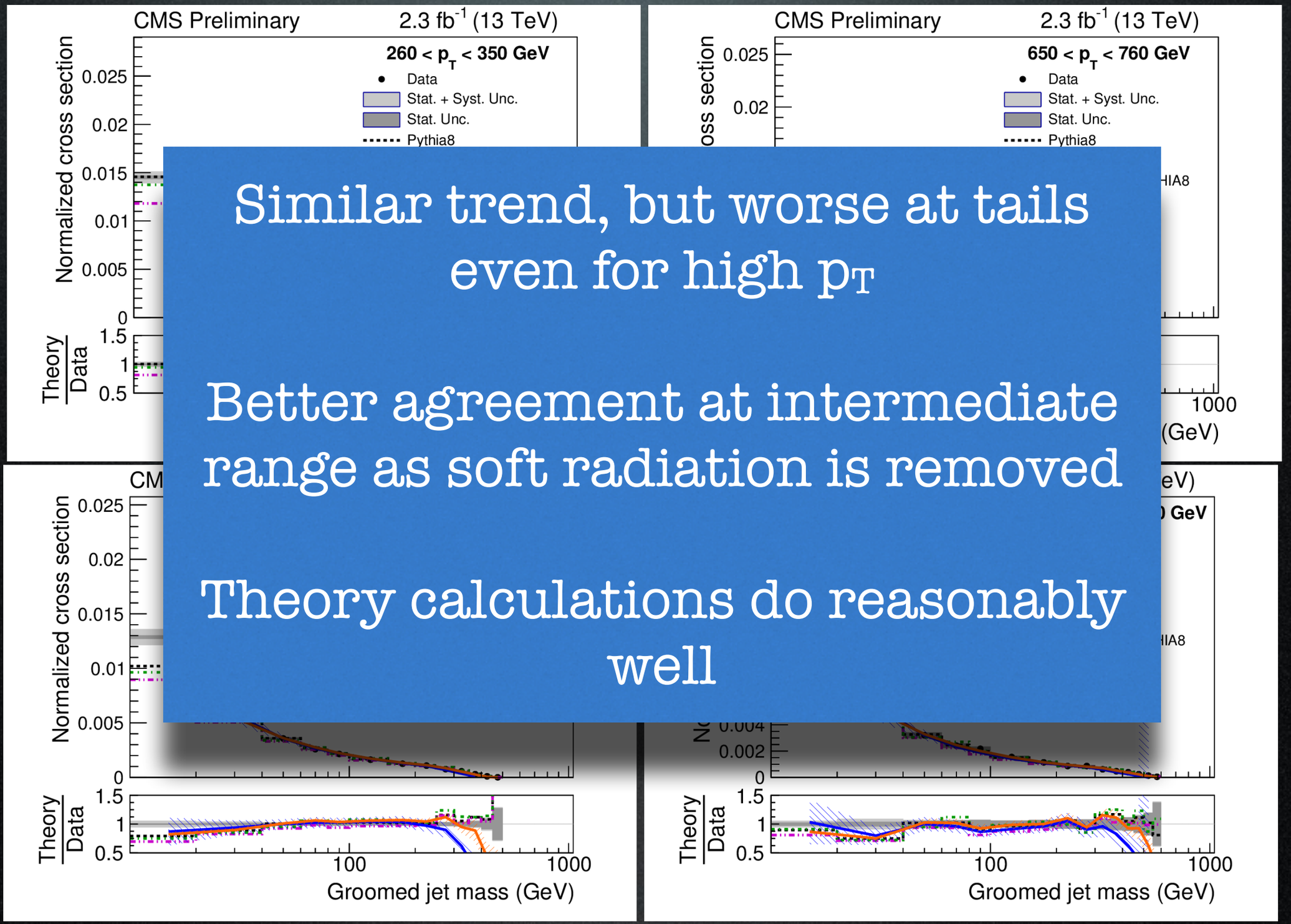






CMS-PAS-SMP-16-010

Soft-dropped Jet Mass



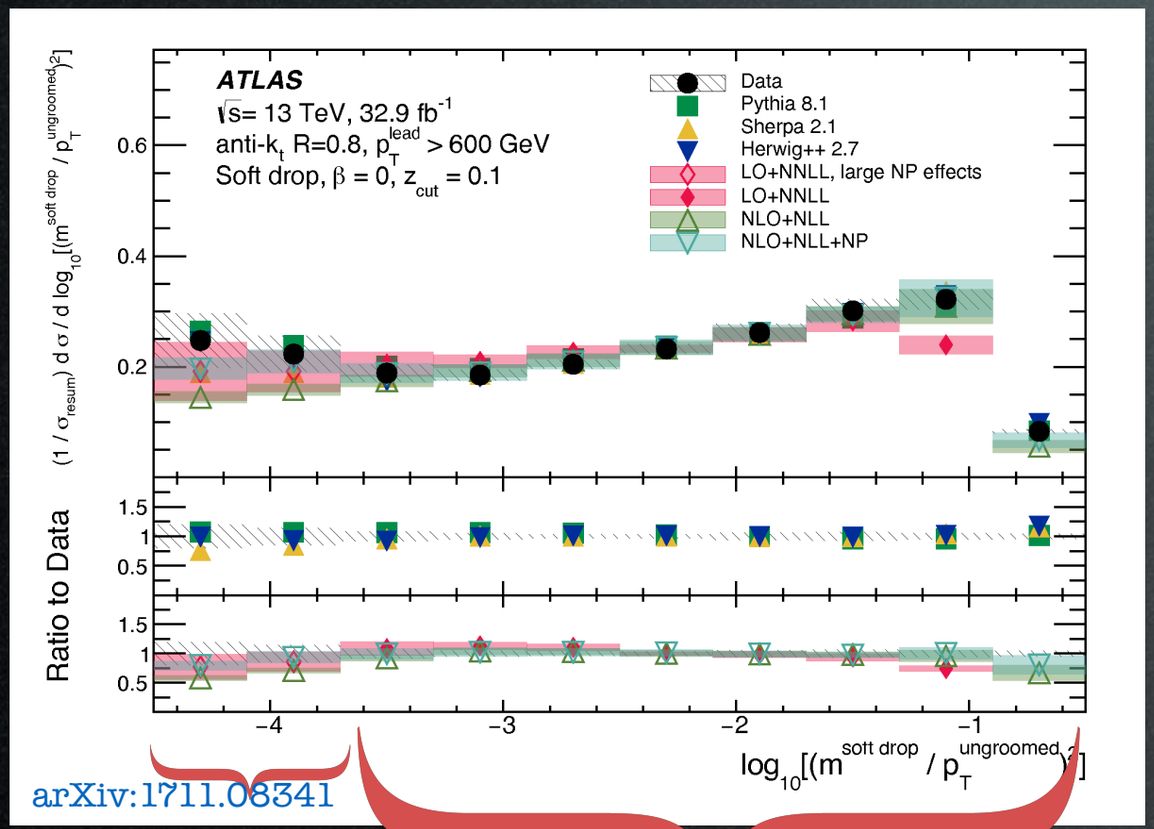
Similar trend, but worse at tails even for high p_T

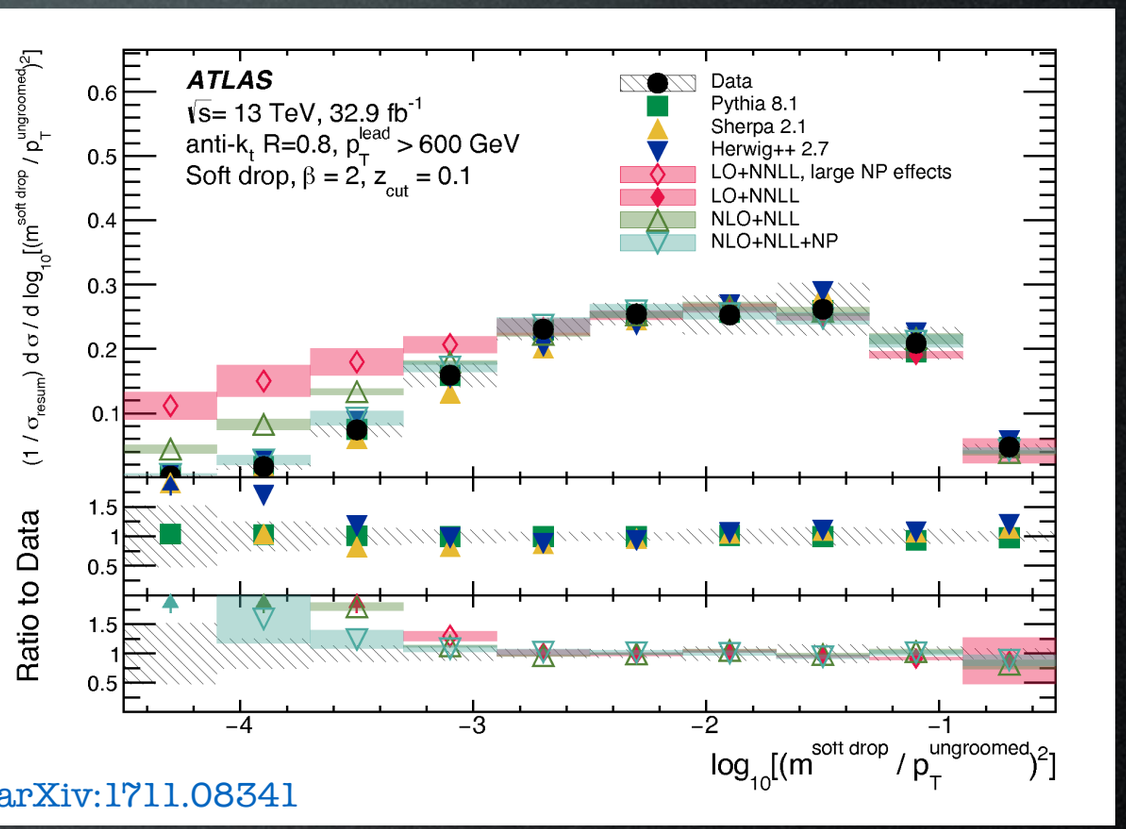
Better agreement at intermediate range as soft radiation is removed

Theory calculations do reasonably well

Soft-dropped Jet Mass

Ratio of the soft-drop mass to the ungroomed jet transverse momentum





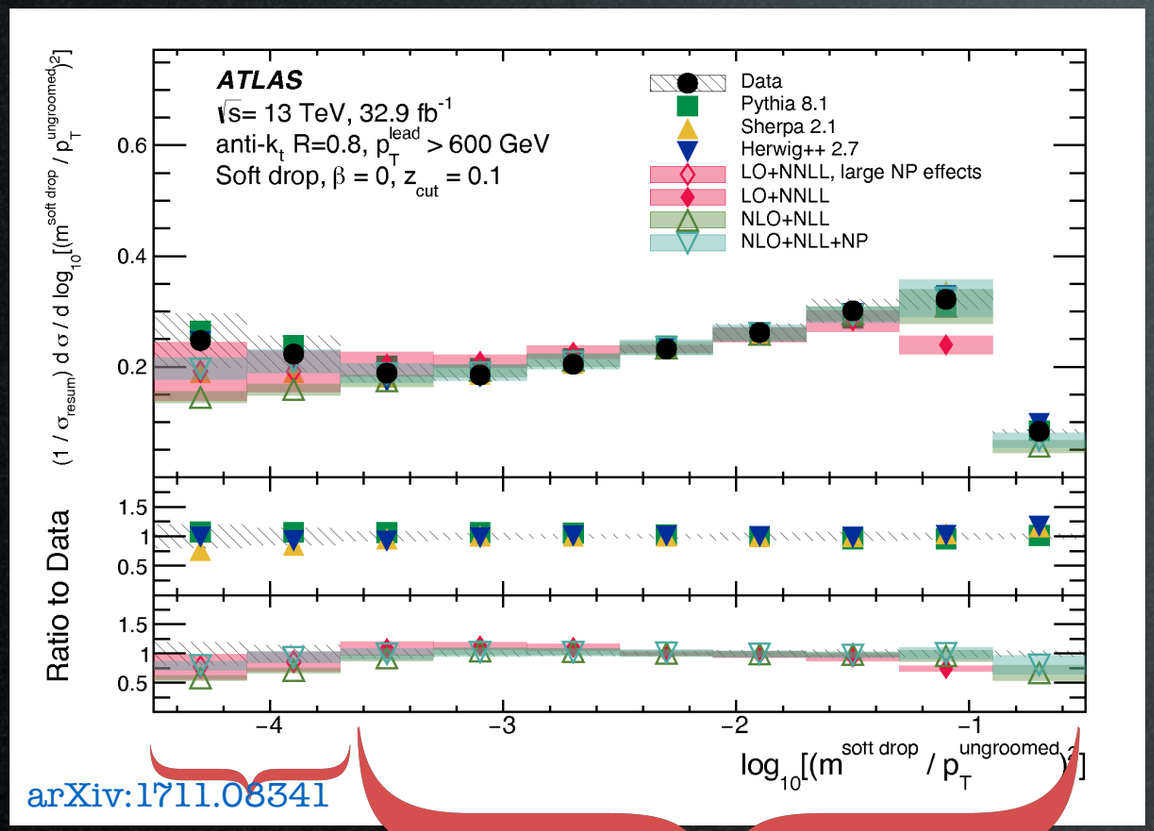
Collinear emission region

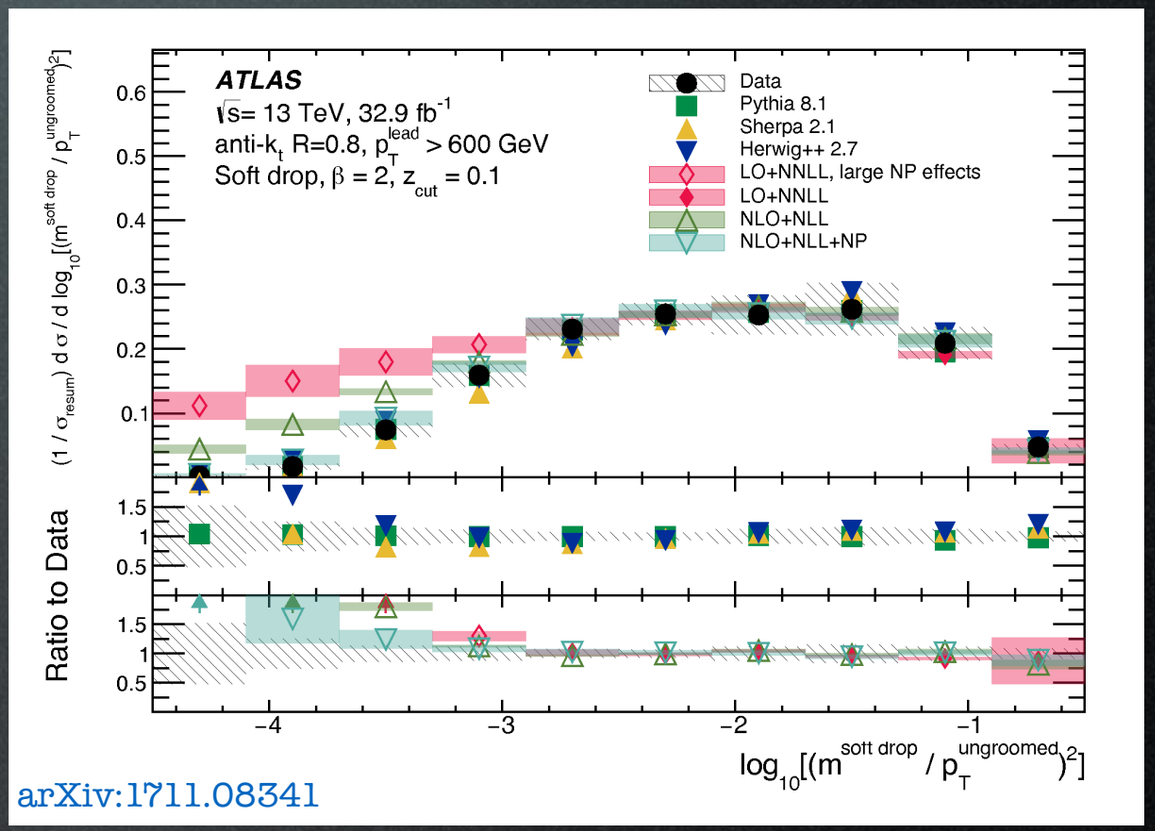
Resummation region

Higher beta
(smaller fraction of soft energy removed)

Soft-dropped Jet Mass

Ratio of the soft-drop mass to the ungroomed jet transverse momentum



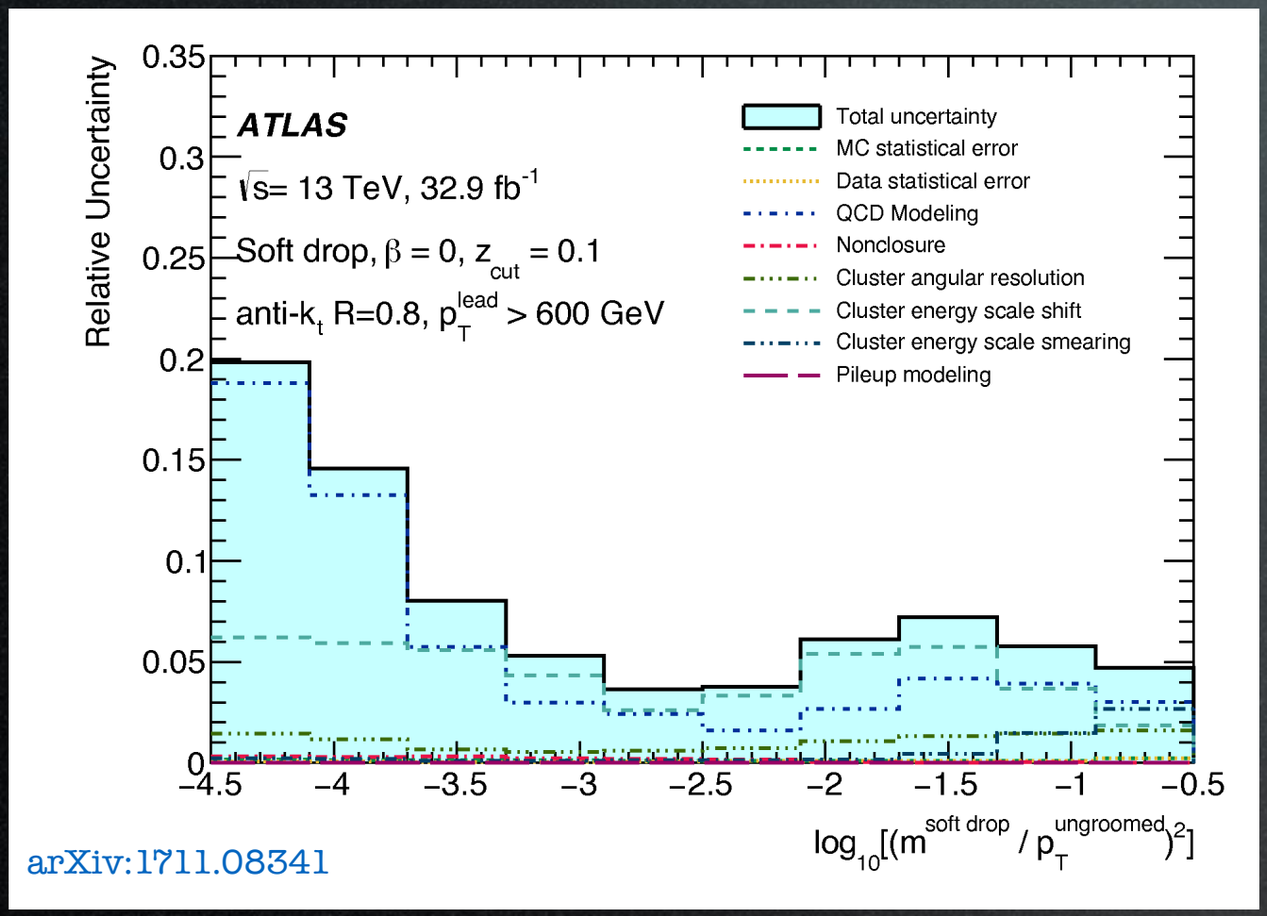


Largest difference between MC and analytic calculation in NP region

NLO+NLL+NP better at low logρ

Good agreement at resummation region for both MC and calculations

Uncertainty for JSS measurements



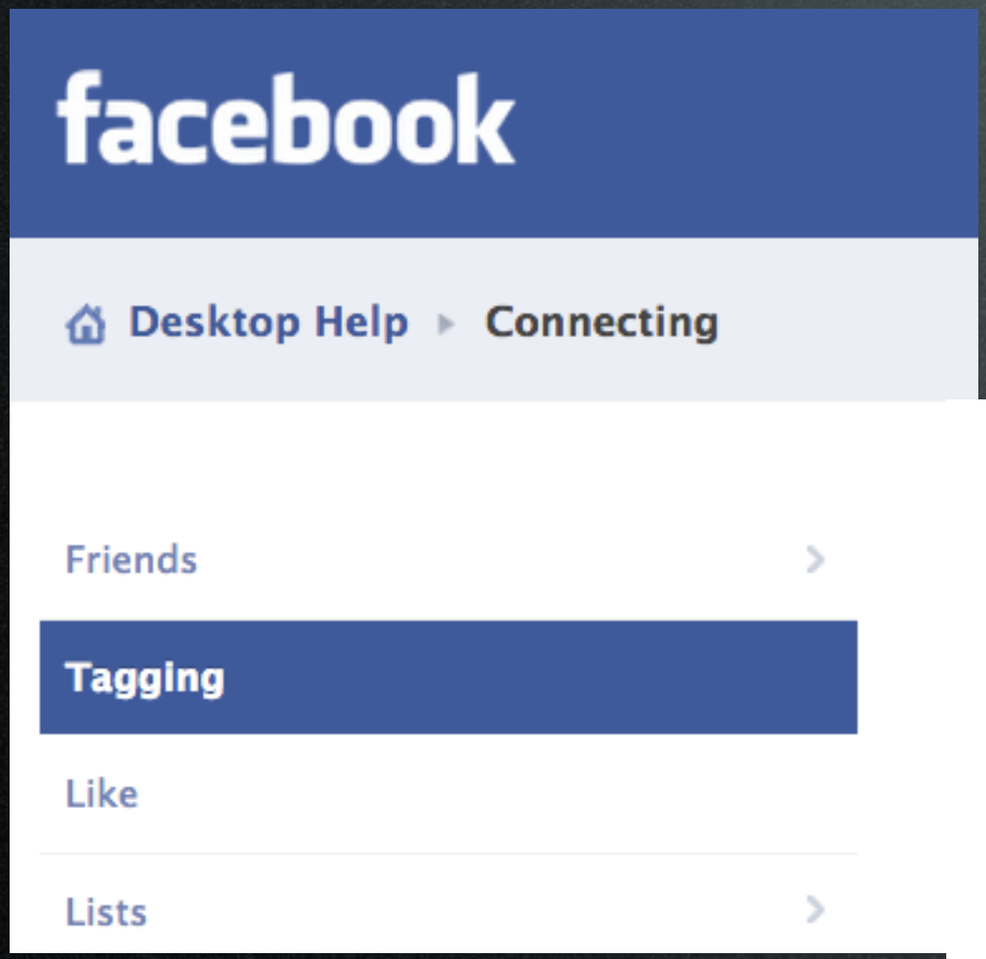
arXiv:1711.08341

Leading experimental uncertainty from calorimeter cell-cluster energy, resolution, efficiency etc.

Cluster energy scale and resolution uncertainties estimated by track to cluster E/p ratio, angular resolution uncertainty by relative position shift

Reconstruction efficiency from unmatched tracks to clusters

Tagging Boosted Objects: observables and taggers

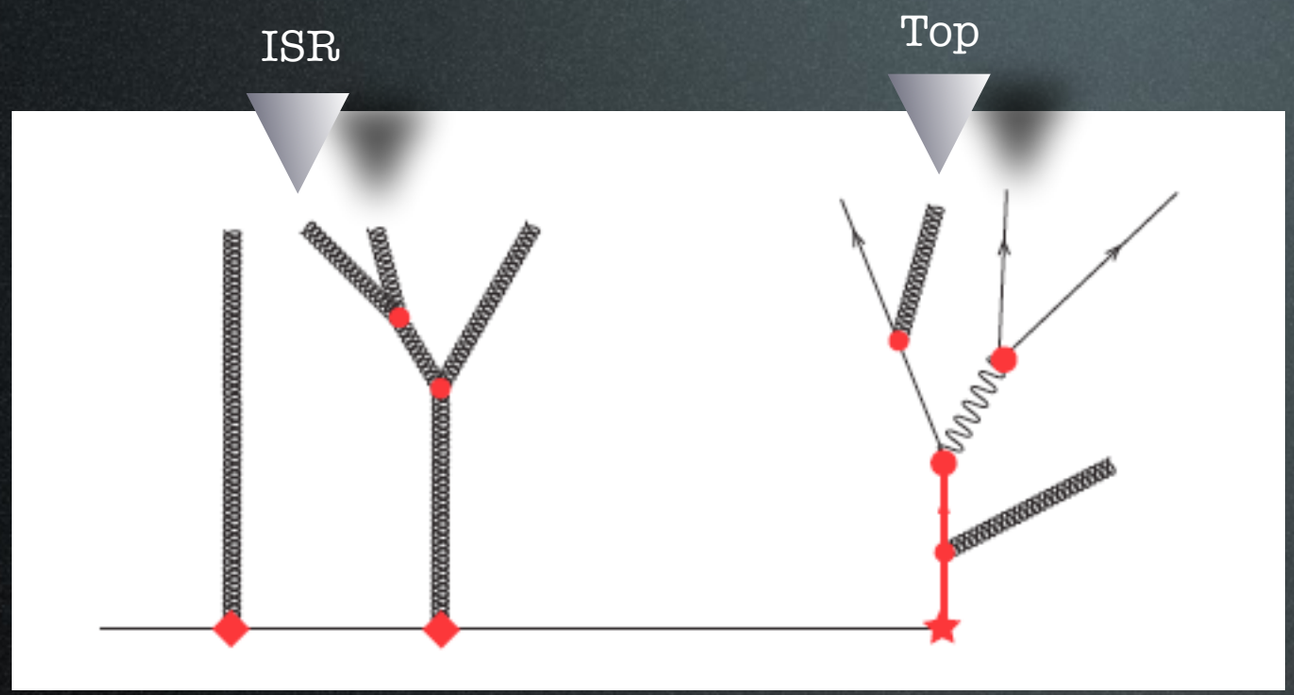


particles

Target is to identify jets resulting from the decay of top quark or Higgs against jets coming from light quark/gluons.

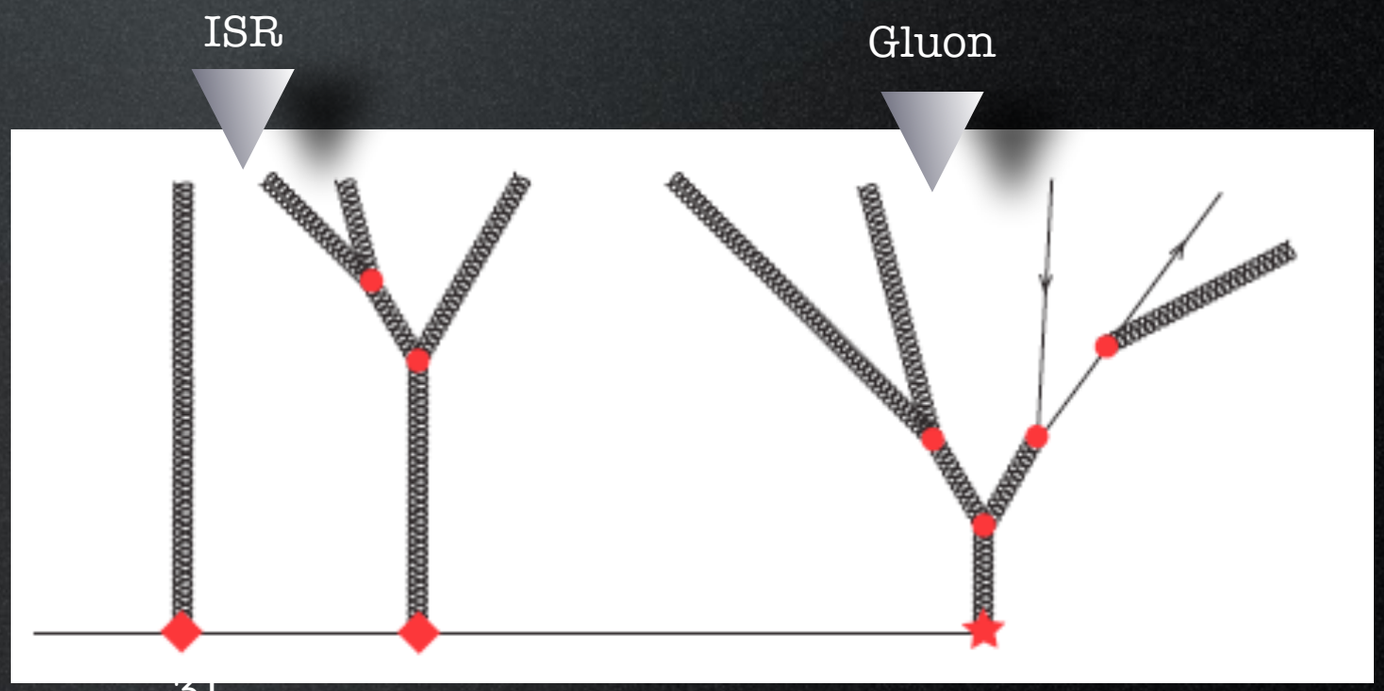
Davison E. Soper, Michael Spannowsky; arXiv:1102.3480, arXiv:1211.3140

Shower Deconstruction



Top quark jet shower history

vs.

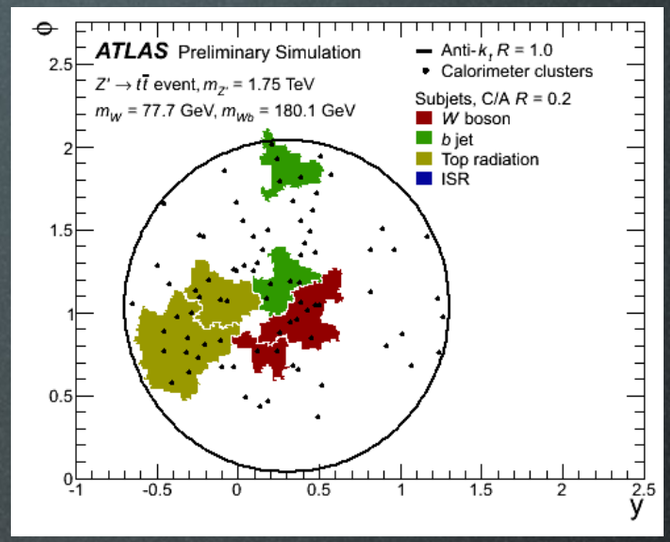


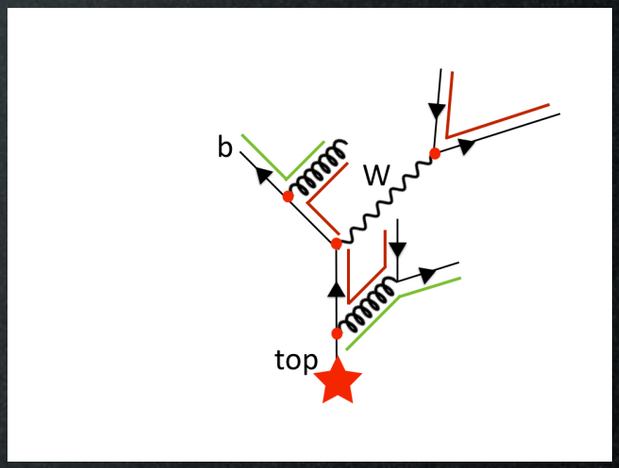
Light quark jet shower history

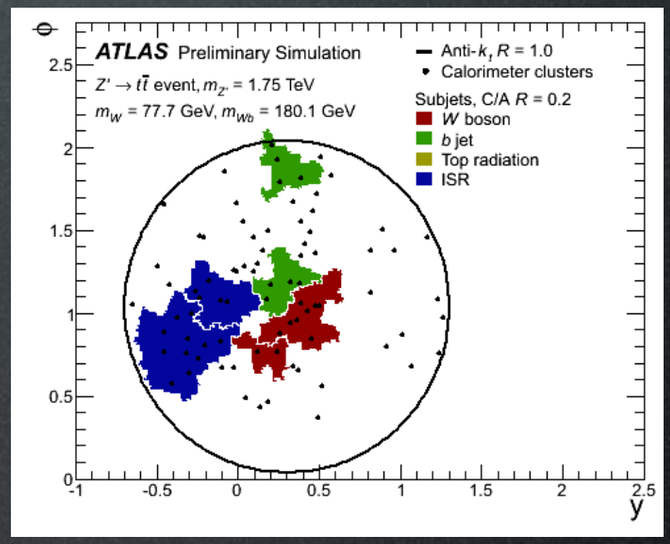
Shower Deconstruction

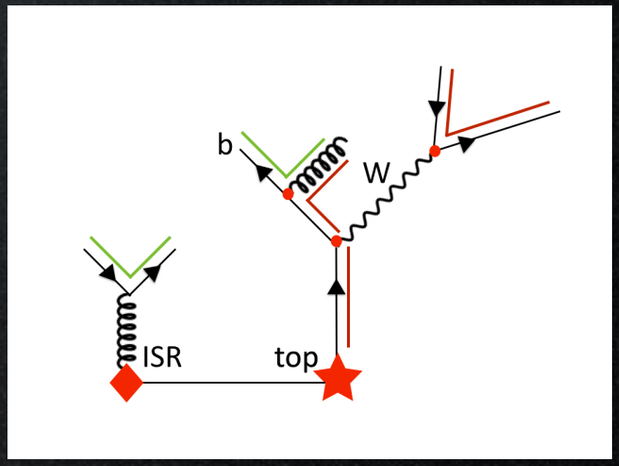
- Decompose the large-radius jet into small radius **subjets.**
- Build all possible shower histories with the subjets.
- Assign probability whether signal-like or background-like.
- A single analytic function:

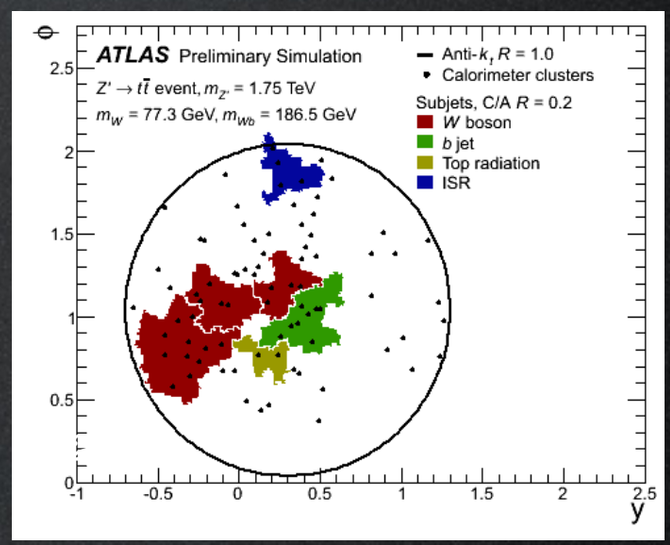
$$\chi(\{p\}_N) = \frac{P(\{p\}_N|\mathrm{S})}{P(\{p\}_N|\mathrm{B})}$$

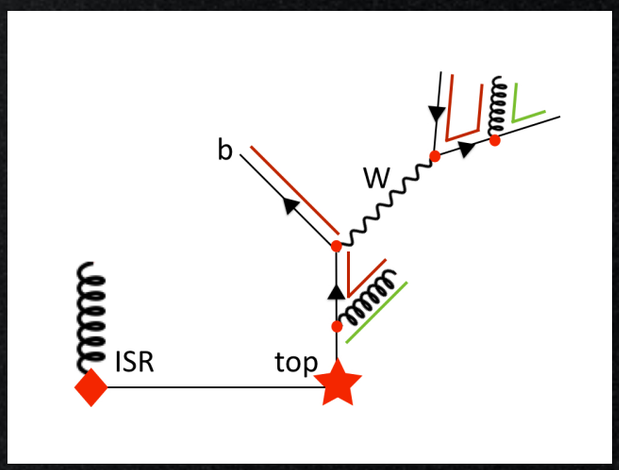








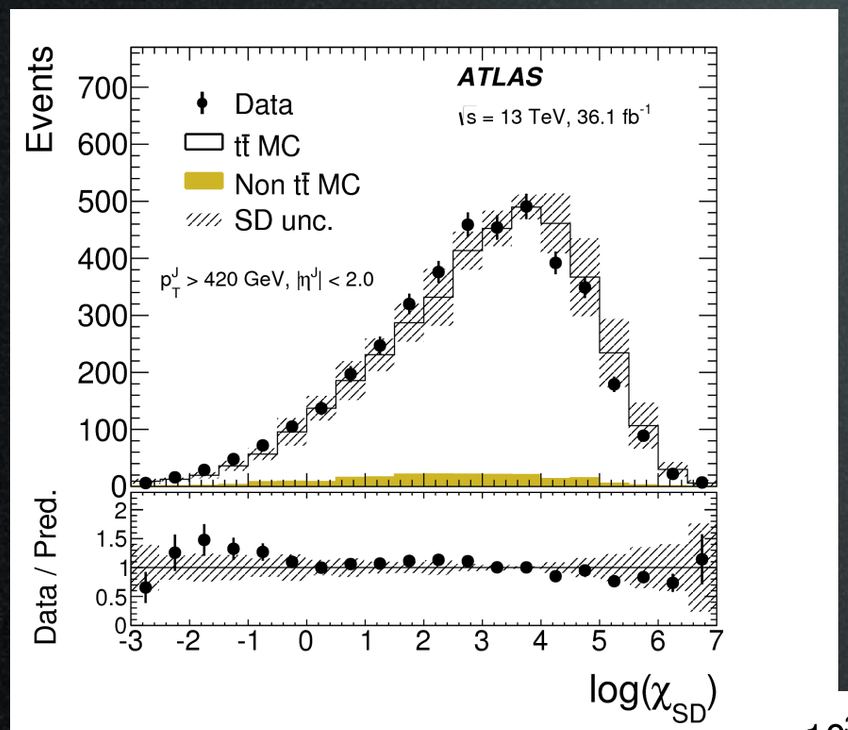




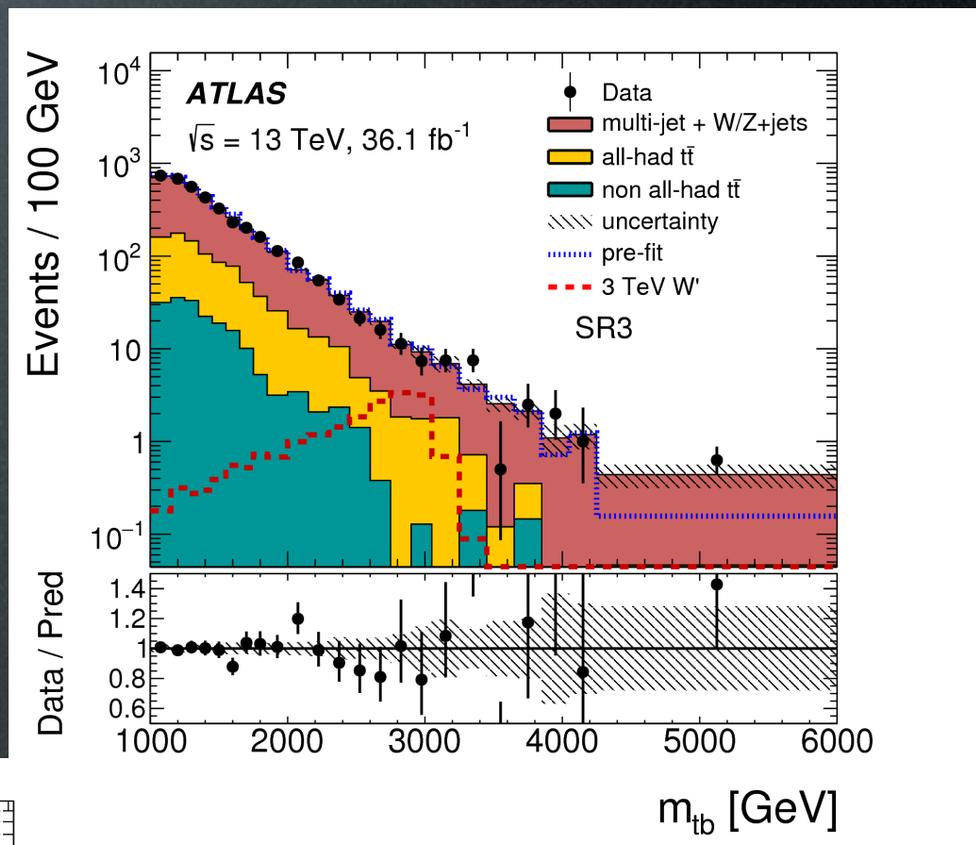
ATLAS-CONF-2014-003

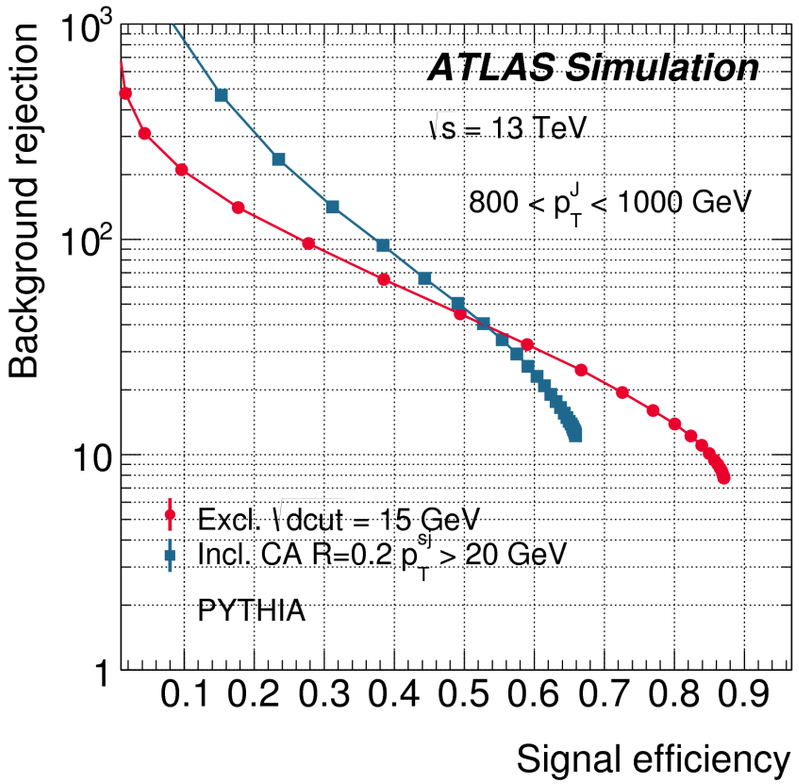
Phys. Lett. B 781 (2018) 327

All hadronic W' search



First result using SD



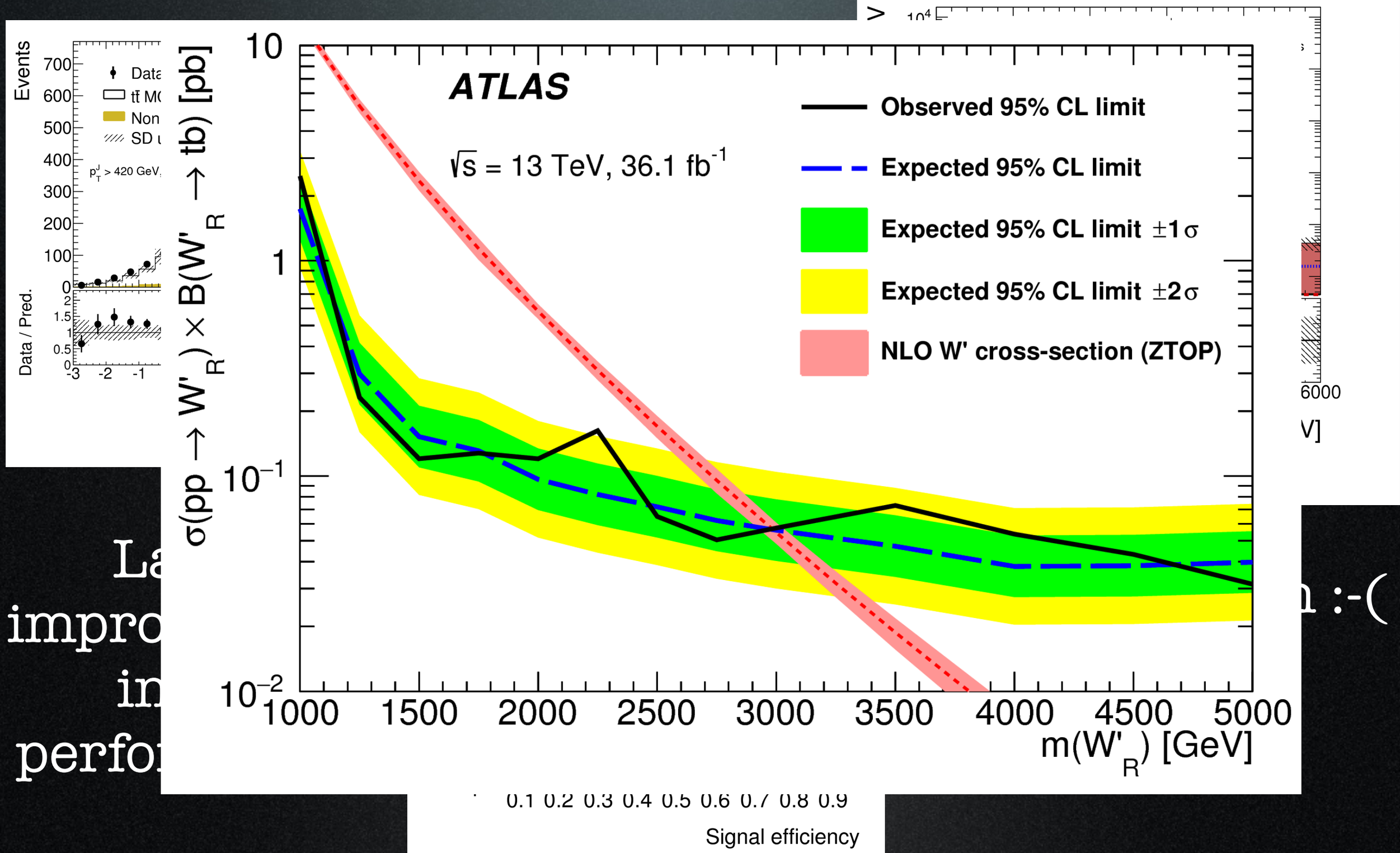


Large improvement in SD performance

No excess seen :-(

Phys. Lett. B 781 (2018) 327

All hadronic W' search



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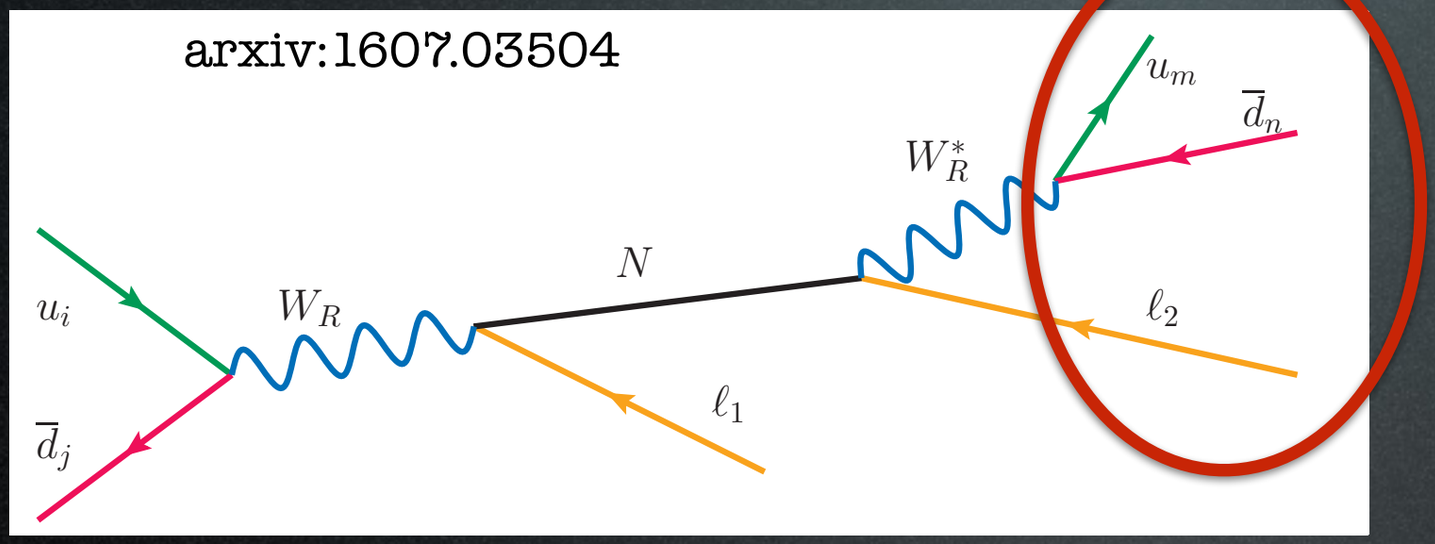
Unusual Topologies: electron in a large-radius jet



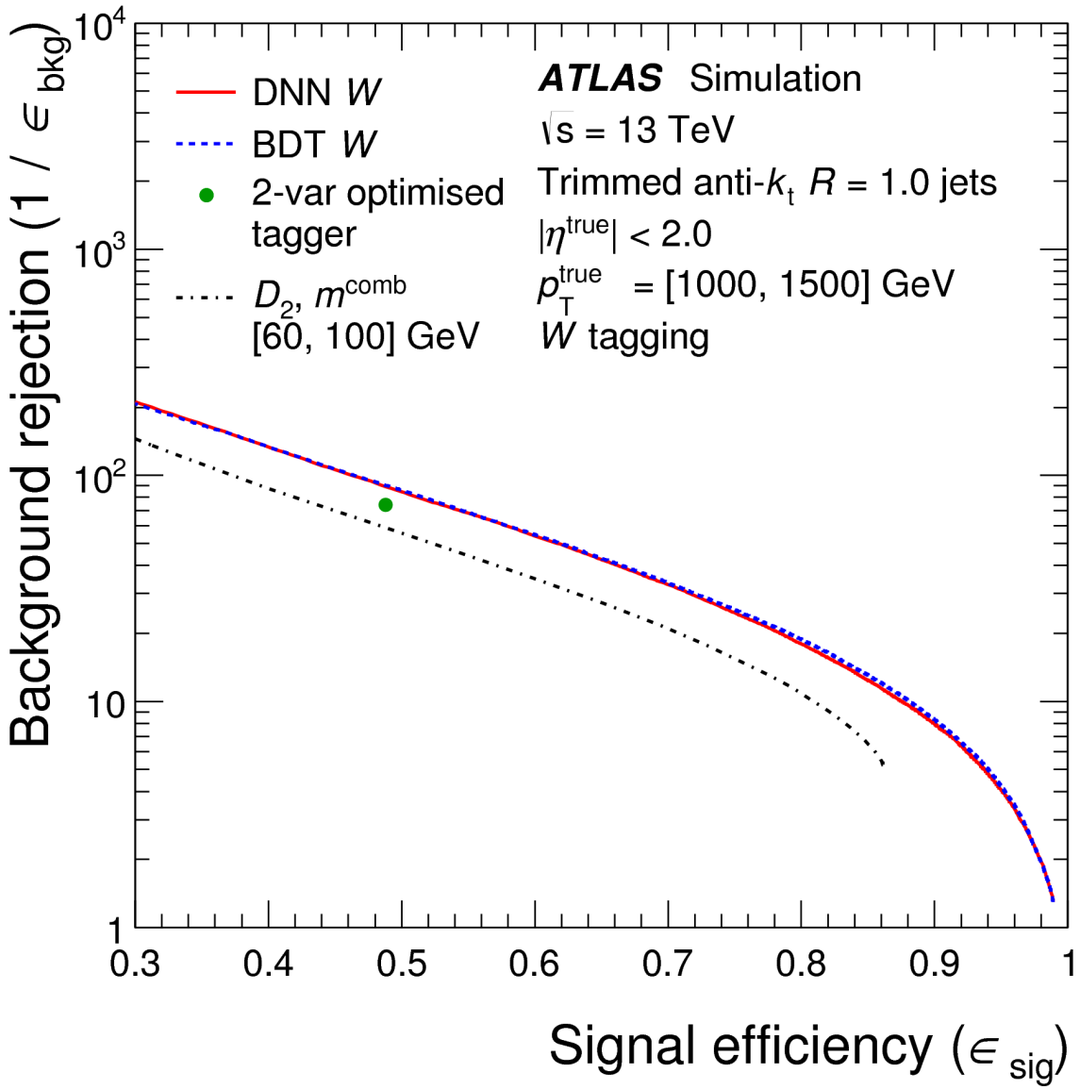
Boosted heavy neutrino in electron channel: large radius jet is the proxy for NR

In ATLAS electron reconstruction assumed no nearby real jet, and applies implicit isolation requirement. That reduces signal efficiency, and the presence of such a jet affects the electron performance numbers

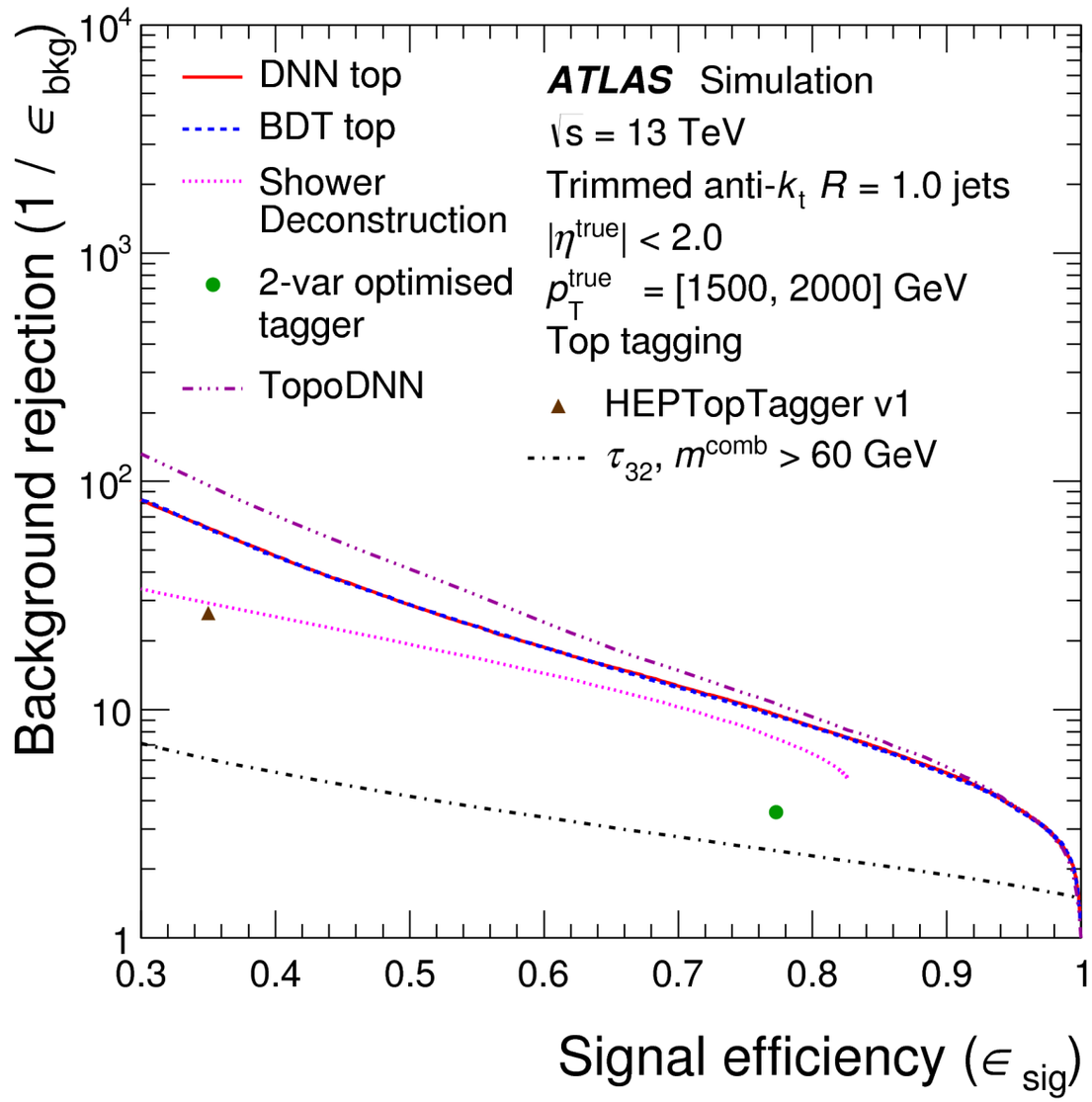
Other new physics signatures with a non-isolated lepton as well. Substructure with electrons is unexplored experimentally!

arXiv:1808.07858

Tagger Comparisons



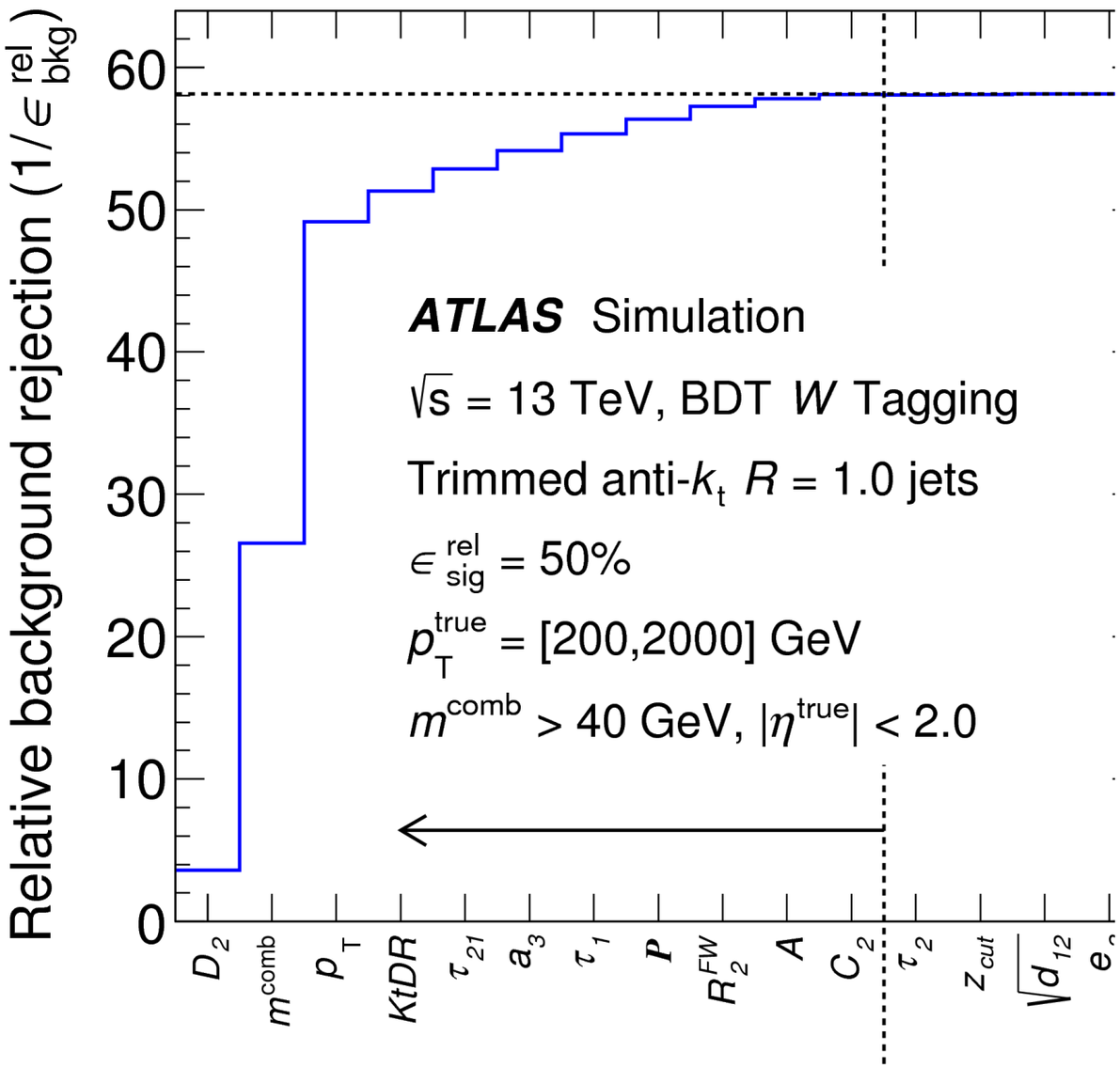
W-tagging

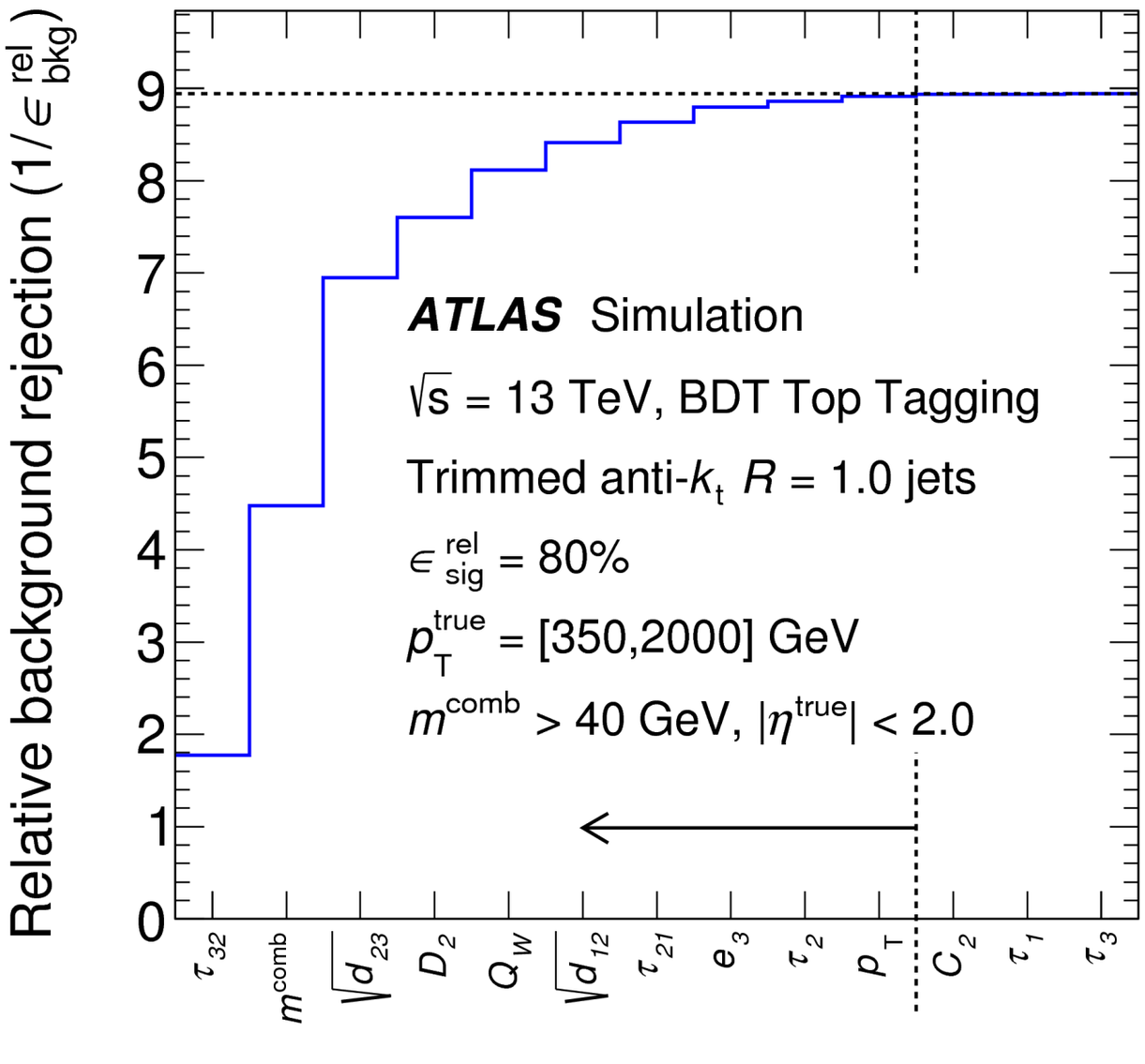


Top-tagging

arXiv:1808.07858

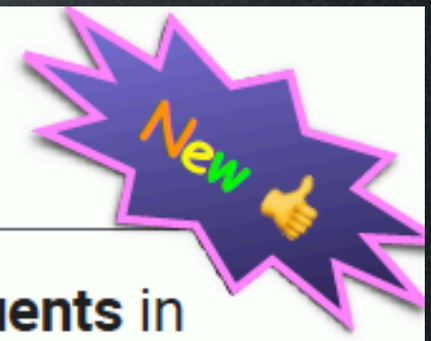
Taggers using Machine Learning





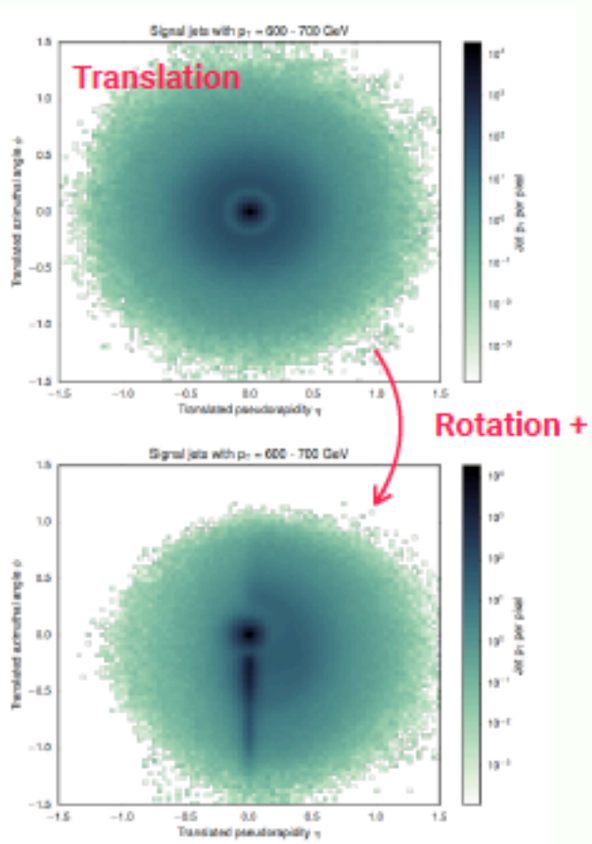
From Andreas Søgaard (Boost 2018)

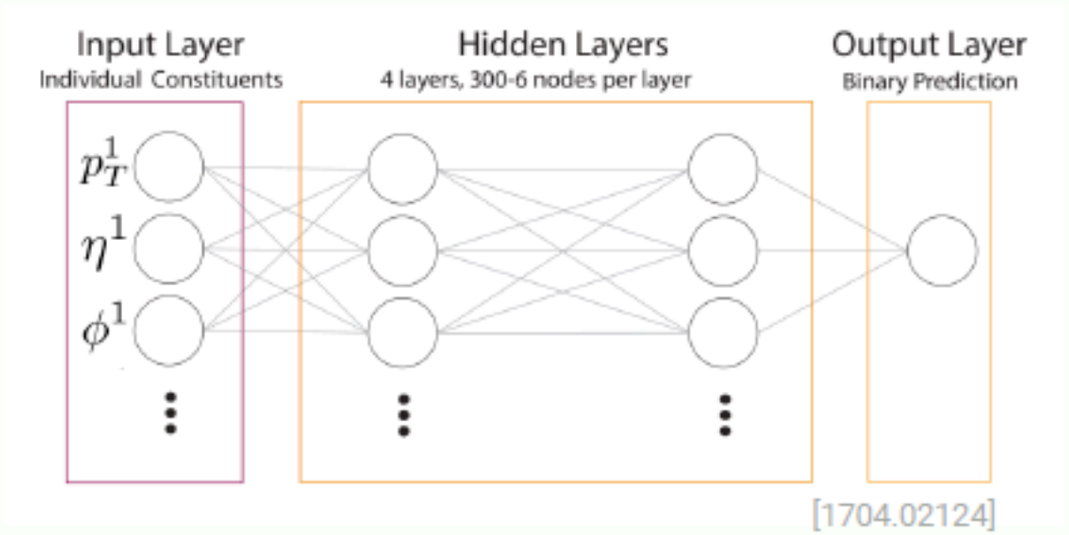
TopoDNN tagger



- Using (p_T, η, φ) of **10 leading LC topo cluster constituents** in trimmed large-*R* jet ($m_{\text{cluster}} \rightarrow 0$)
- Preprocessing: **translation**, **rotation**, and **flip** of assumed three-subjet topology

[1704.02124]





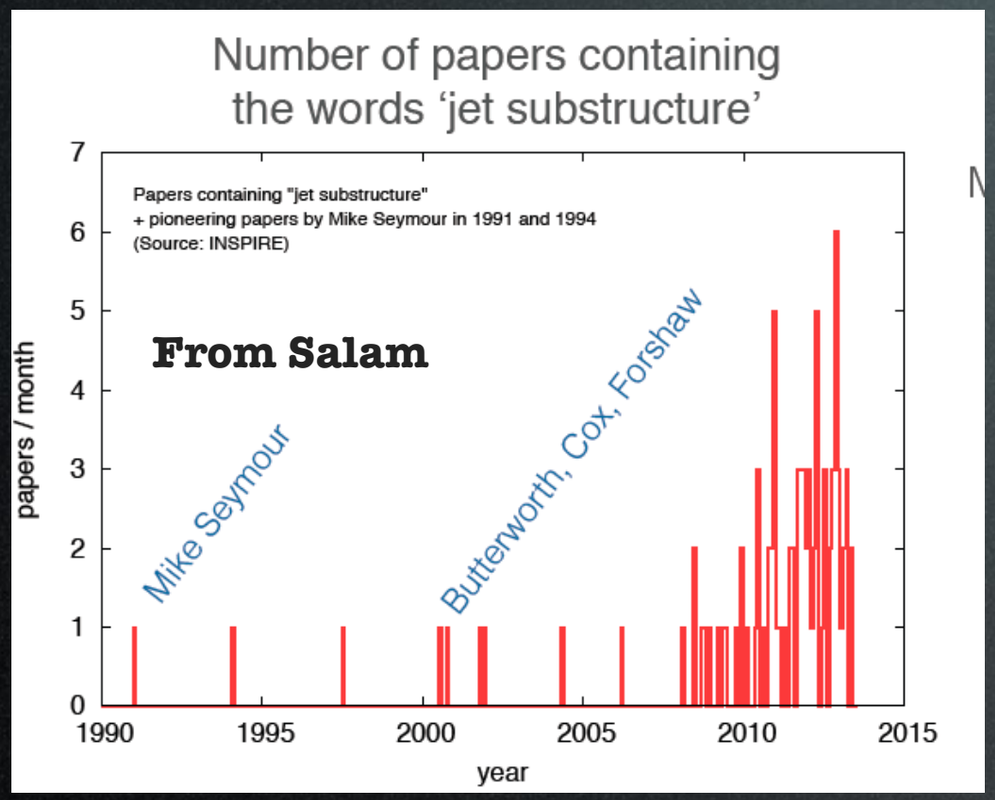
[1704.02124]

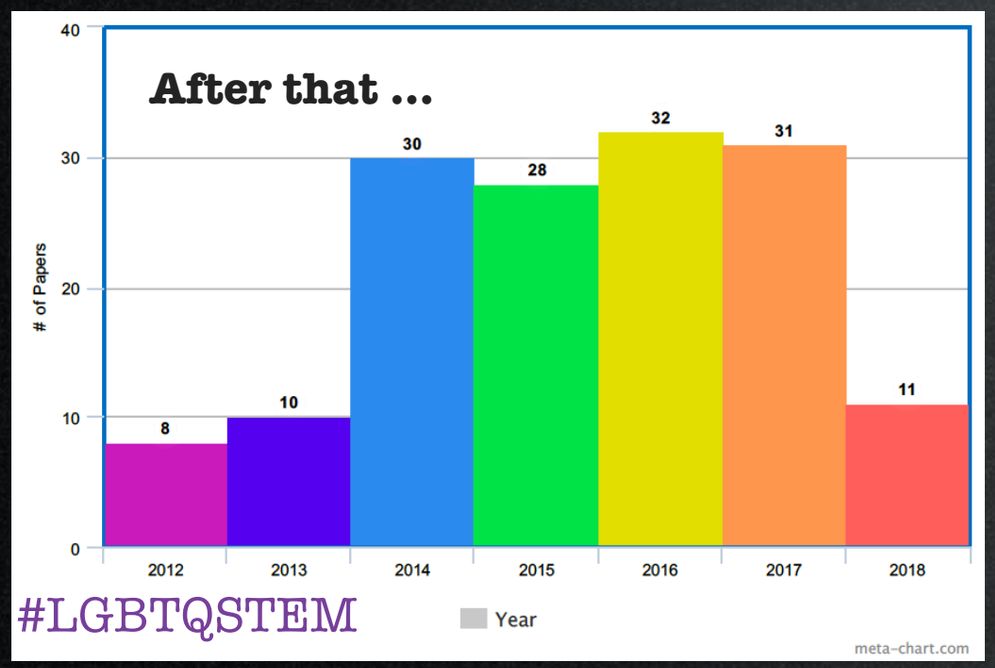
9

Epilogue: still not used in experiments

- Considered blackbox by many
- No robust way to estimate experimental systematics.
- Correlations are hard to estimate, and not always linear.

Looking Forward





- Jet substructure studies are essential for finding new physics in post-Higgs era in (HL) LHC and ILC.
- Need measurements, and best possible MC modelling
- Proper estimation of uncertainties, and robustness against pileup is critical