New physics searches with boosted tops at ATLAS

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On behalf of the ATLAS collaboration

LPCC workshop “from the charge asymmetry to the boosted regime”

CERN, May 2nd to 4th 2012

Boosted top quarks?

Do we need to bother at all?

A: what is a boosted top quark?
B: are they particularly relevant for LHC physics?
C: can we show boosted top quarks after two years of data?
D: do boosted-top reconstruction tools really work?
    Better than general-purpose algorithms?
E: show me an analysis on boosted top quarks!

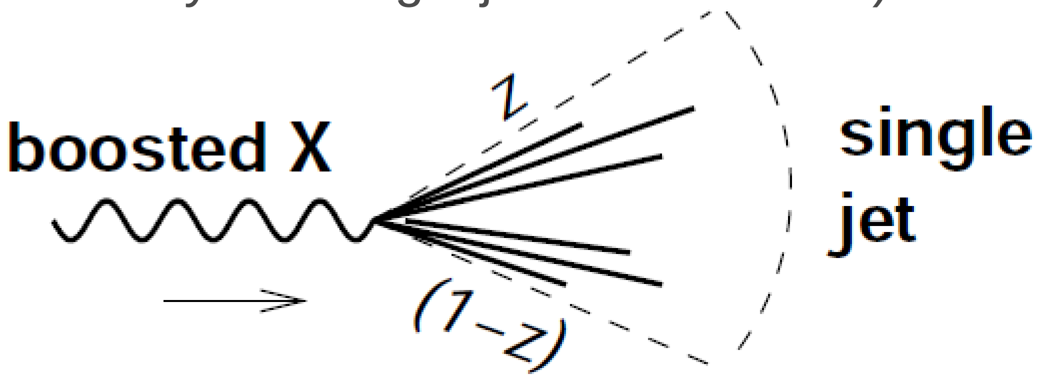
Boosted object: definition

Let's define "boosted object" by comparing the standard approach (reconstruct components and combine) **to Mike Seymour's alternative** (find composite object and decompose).

Rules of thumb for maximum jet radius parameter for 2-body decay:

$R < 2m/p_T$ (always resolve two jets)

$R > 3m/p_T$ (capture full decay in a single jet 75% of cases)



W boson at rest → use resolved approach

p_T ~ 240 GeV → coexisting algorithms,

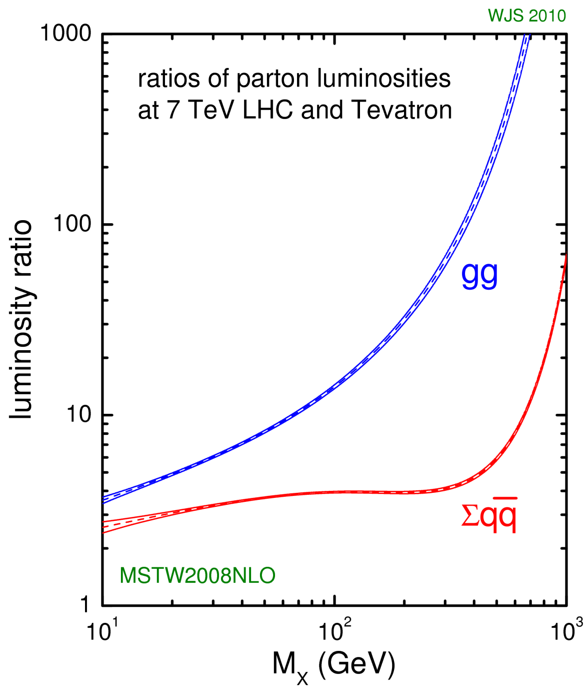
can resolve with R=0.4, or contain in R=1

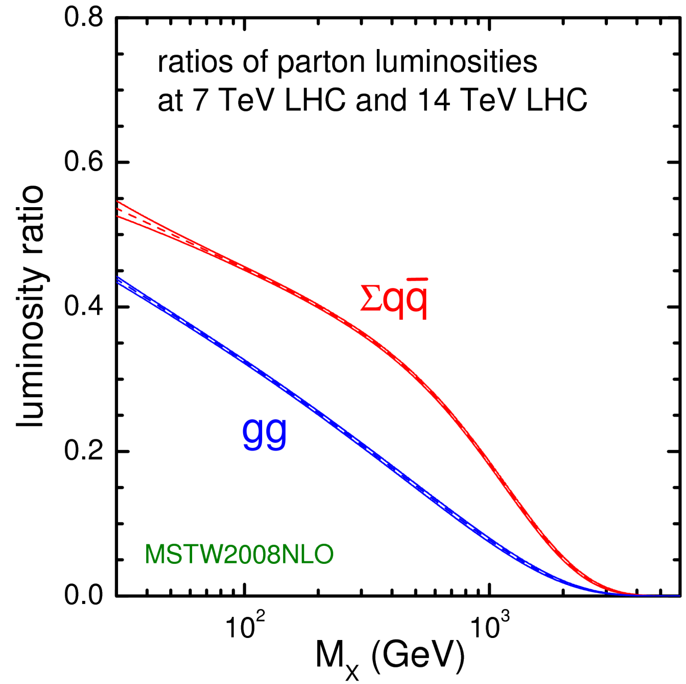
p_T ~ 400 GeV → boosted regime

cannot always resolve with R=0.4

Welcome to the TeraScale!

With the LHC we enter a new kinematic regime, even at 7 TeV





Parton luminosity at 1 TeV 2-4 orders of magnitude higher than at the Tevatron. Even for the heaviest SM particle many events will be found in the boosted regime

Physics potential: are boosted top quarks particularly relevant for the LHC program?

Hoping to directly observe a new source:

- something at the TeraScale (e.g. Z') decays to something at the electro-weak scale (t,W/Z,H,. . .) that decays to N jets

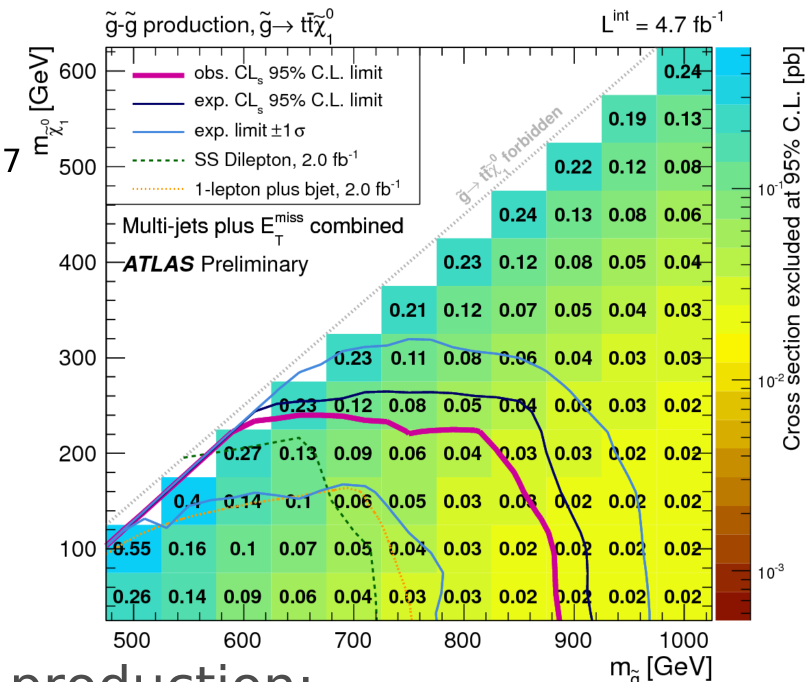
X → tt, b' → tW, W' → tb...

remainder of this presentation

g → tt χ_0

6-9 jets and Etmiss significance, ATLAS-CONF-2012-037

Boosted Tops from Gluino Decays, 1111.6594



Even for non-resonant production, one may look for a region with less background and/or ambiguities

ttH → Plehn, Salam, Spannowsky '09

Many handles on study of top quark production:

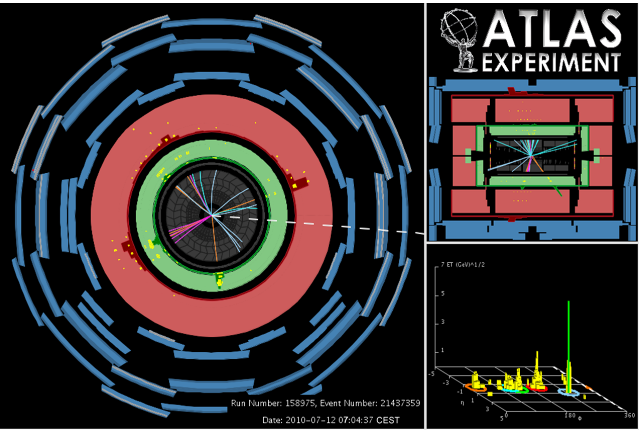
- same-sign tops,
- charge asymmetry
- polarization
- spin correlations

Top – three regimes

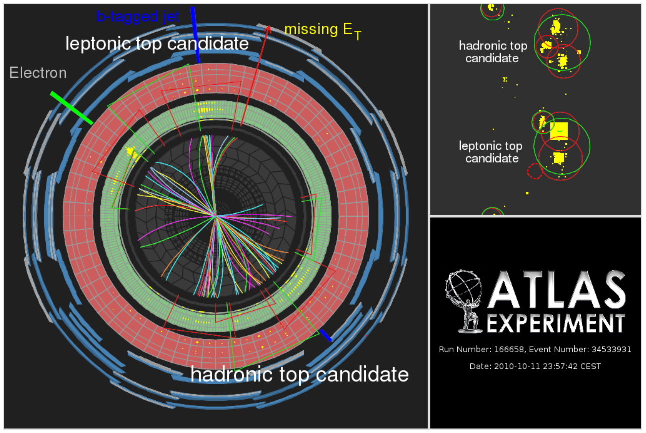
Can we show they exist?

...

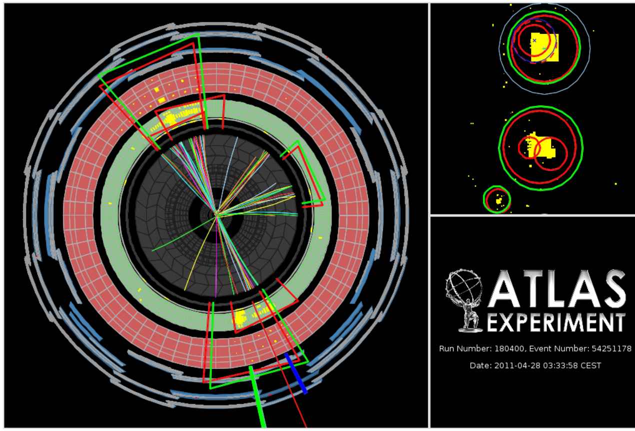
We do have some rather compelling event displays



Early “l+jets” candidate
ATLAS-CONF-2010-063



First boosted top quark
ATLAS-CONF-2011-073



m_{tt} > 1 TeV
ATLAS-CONF-2011-083

Note that these are “certified” ttbar events, that stem from analyses with well-documented ttbar purity

Boosted tops

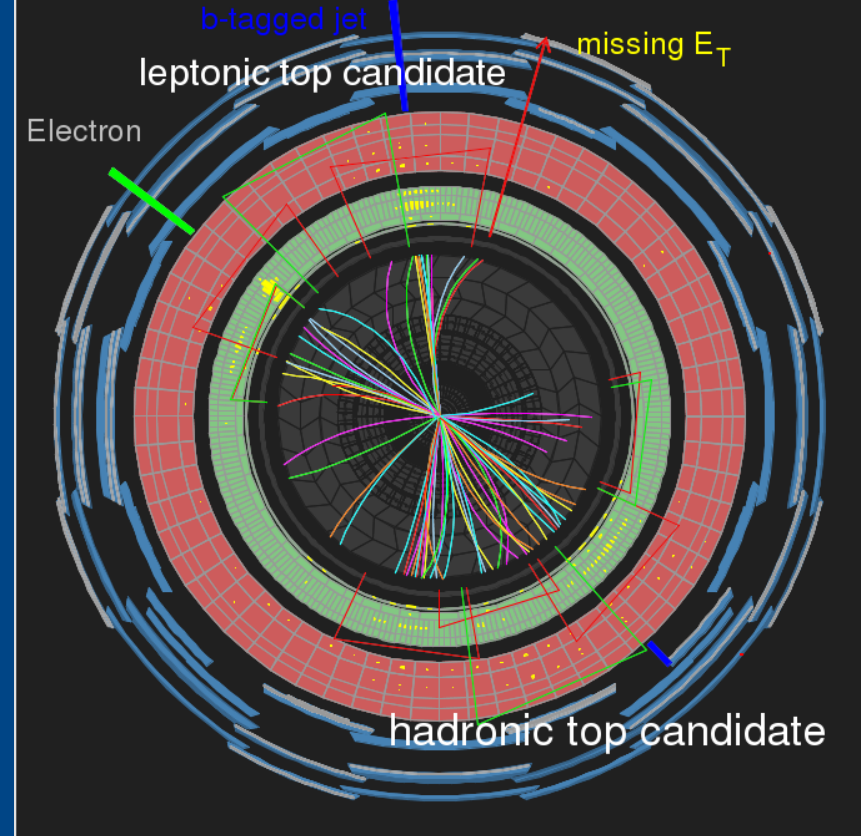
2010 data: the first five events of what will become an excellent control sample

When reclustered with R = 1.0 three jets merge into a single "fat" jet with:

m_j = 197 GeV (expected: m_t)
sqrt(d_{12}) = 110 GeV (expected ~m_W)
sqrt(d_{23}) = 40 GeV (expected ...)

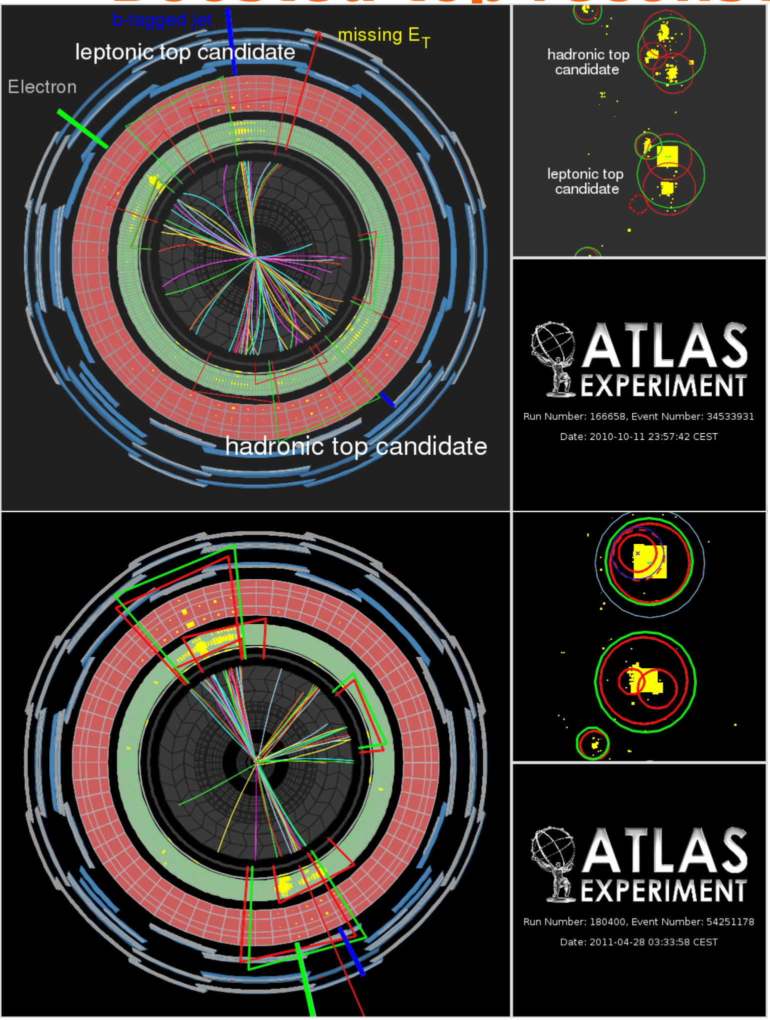
Matching small and large jets we can transfer the small uncertainties of the well-known jets to less well-know ones

Measurement of Jet Mass and Substructure for Inclusive Jets in √s = 7 TeV pp Collisions with the ATLAS Experiment, ATLAS-CONF-2011-073



Resolved for R=0.4, Boosted object for R=1

Boosted top reconstruction

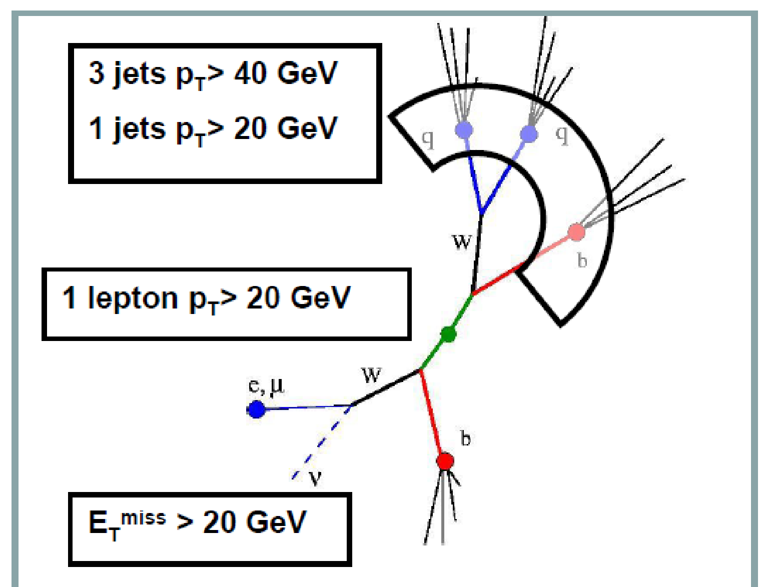


ATLAS-CONF-2011-073

Can use the clear correlation between directions when assigning jets to top quark candidates

anti-k_t with R=0.4 yields only 3 jets

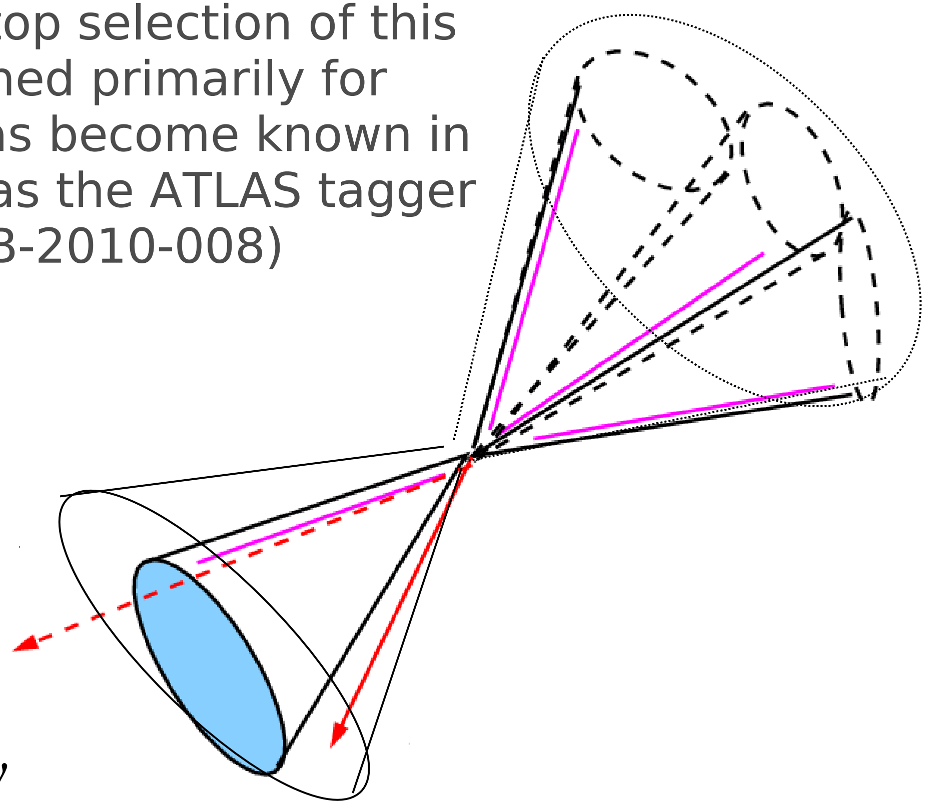
ATLAS-CONF-2011-087



boosted top quark reconstruction

$t \rightarrow bW \rightarrow bjj$
reconstruct a single "fat" jet (R=1-1.5)
measurable substructure (jet mass, splitting scales, ...)

The hadronic top selection of this scheme designed primarily for lepton+jets has become known in the literature as the ATLAS tagger (ATL-PHYS-PUB-2010-008)



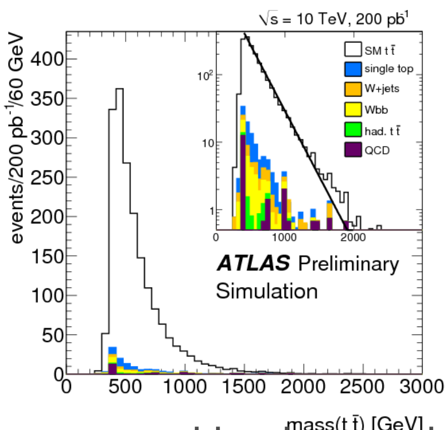
Jet mass = invariant mass obtained when 4-vectors of all jet constituents are added

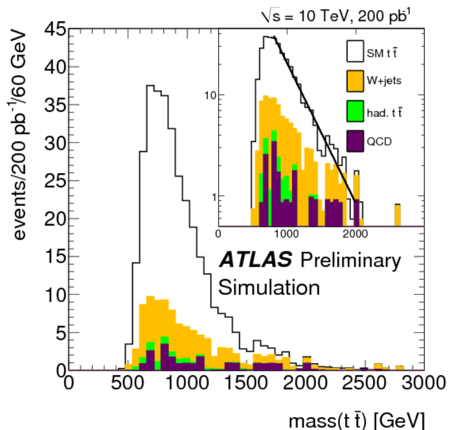
k_t splitting scale

$\sqrt{d_{n\,n+1}}$ = run k_t inside jet, undo last steps, and record k_t distance (scale) of the split from n to n+1 pseudo-jets

$t \rightarrow bW \rightarrow bl\nu$
lepton might not be isolated or even "embedded" in the jet
Alternative isolation variables (Thaler & Wang), mini-isolation (Tweedie)

Top-tagging: for a review, see Plehn & Spannowsky, for a comparison, see Chris' talk





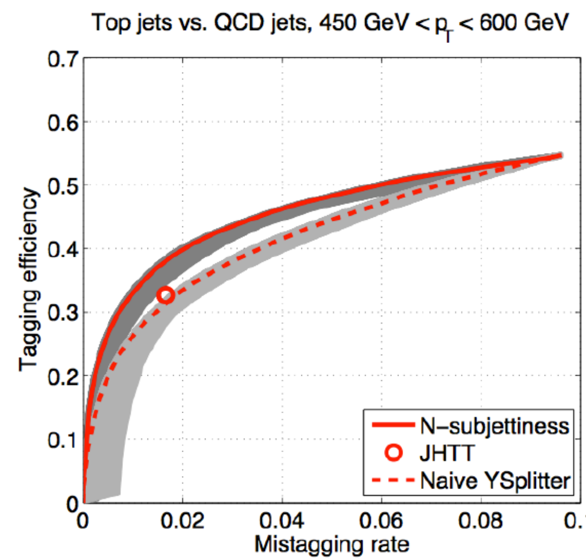
Old plots from our 10 TeV prospects MC note (ATL-PHYS-PUB-2010-008)

Reconstructed background spectrum on MC using an adapted resolved algorithm (stable at 5 % effiecieny up to 2 TeV) and an algorithm developed for boosted top quarks. (15% down to m_{tt} = 700 GeV). Both have comparable mass resolution.

ATLAS supports fat jets and substructure! n-subjettiness (arXiv:1011.2268 [hep-ph], arXiv:1108.2701 [hep-ph]) → Adam's talk

Commissioning the HepTopTagger [arXiv:1006.2833] for fully hadronic final states → Michisa's talk

Template top-tagging → ask Leandro

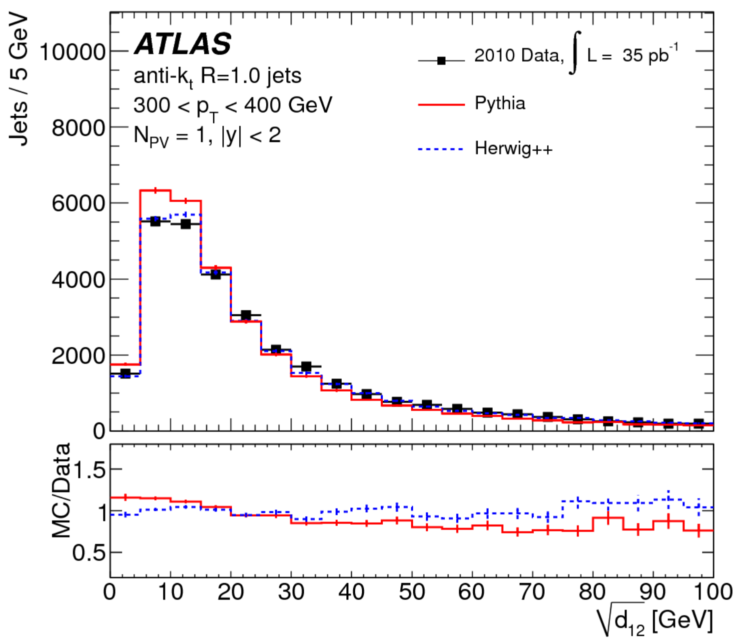


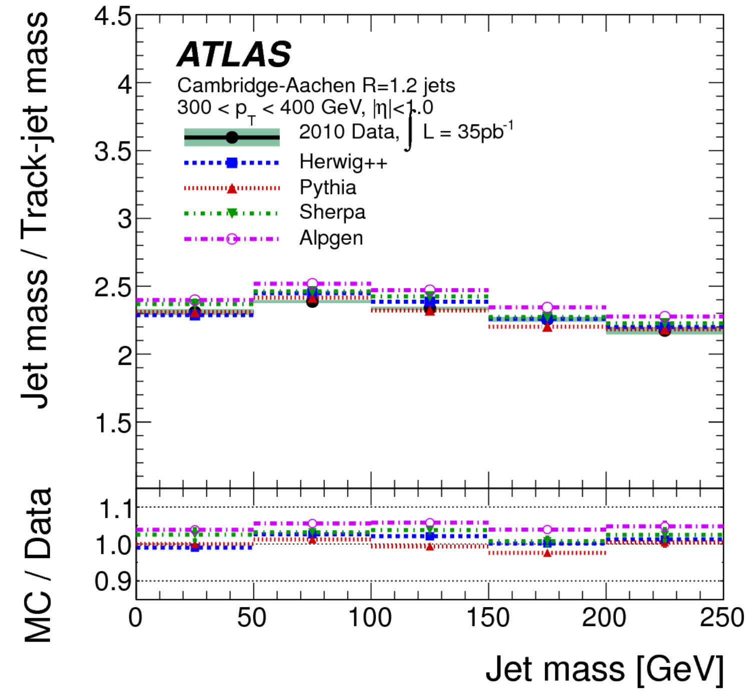
Commissioning jet substructure

The energy and mass calibration and scale uncertainties for the anti-k_t jets with R=1 are based on the work in arXiv:1203.4606 [hep-ex] (Adam Davison's talk in this workshop)

Use locally calibrated topological clusters so that jet-level corrections are small. Determine jet-level corrections on MC to correct reconstructed energy or mass to the scale of matched particle jets

Check the detector-level distribution



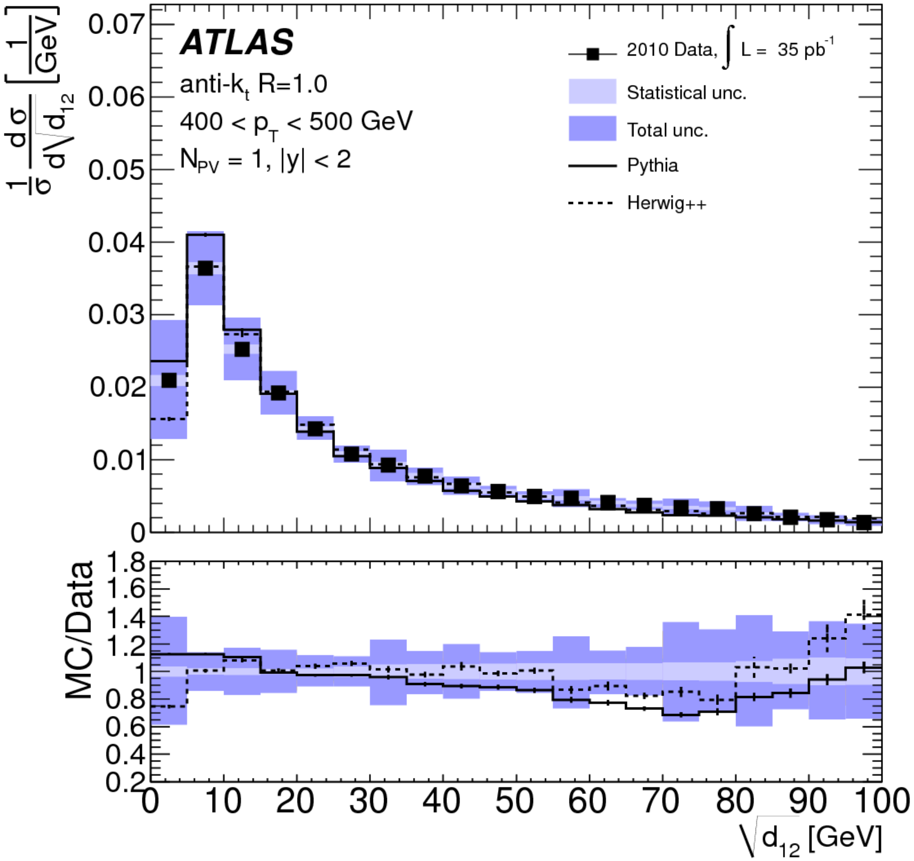


Determine scale uncertainty for E, m and $\sqrt{d_{12}}$ in situ by comparing track and calo jets

Commissioning jet substructure

arXiv:1203.4606 [hep-ex] and Adam's talk

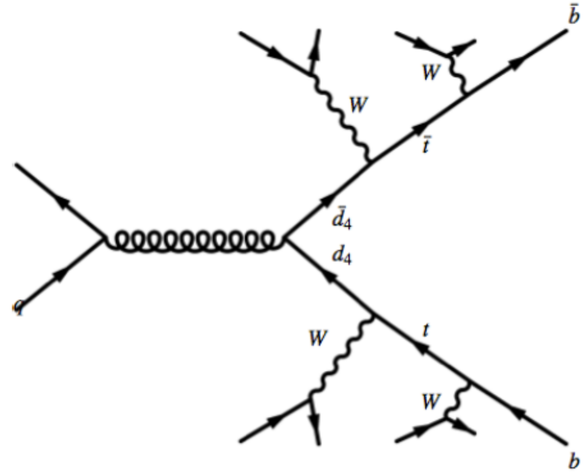
Distribution at “particle-level”, after correcting for all detector effects show reasonable agreement between data and most MC within not-too-large systematic uncertainties:
- Parton Shower model is adequate
- Detector response is under control
- Underlying event OK



What about pile-up?

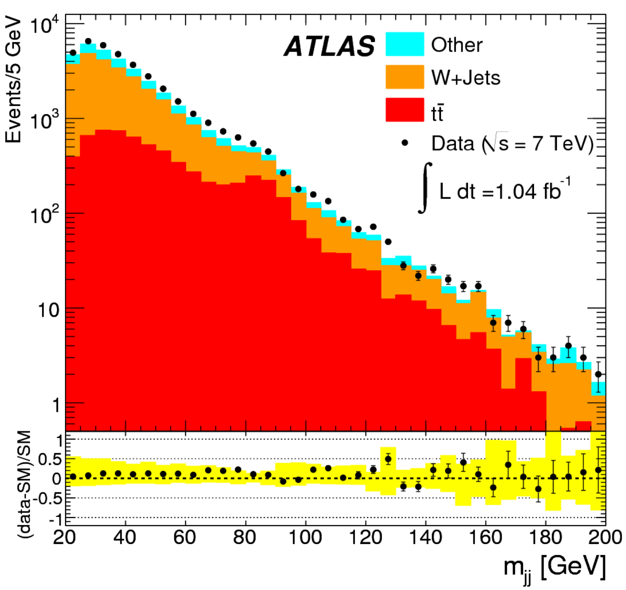
Pile-up has been shown to have a big impact on some substructure observables (most notoriously, jet mass)
We can mitigate the impact on analysis by grooming or smart choice of observables, by correcting using smart techniques, and by modeling pile-up correctly in MC

b' → Wt

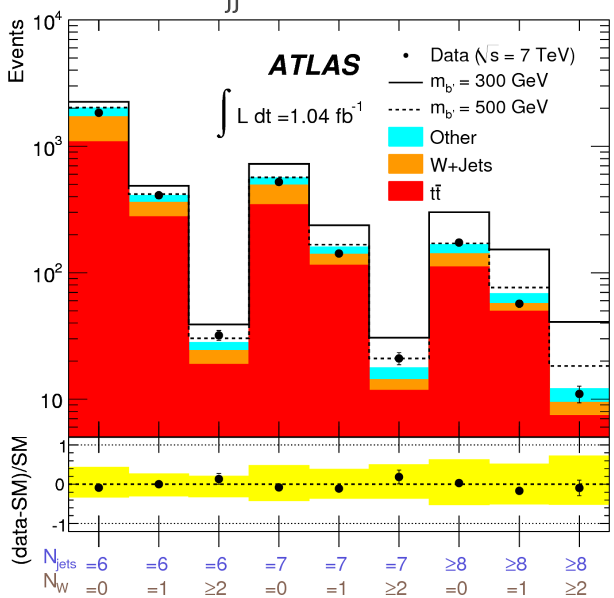


“Boosted objects without substructure”
(ATLAS b' search in arXiv:1202.6540)
Signal: tt pair + 2 boosted W bosons

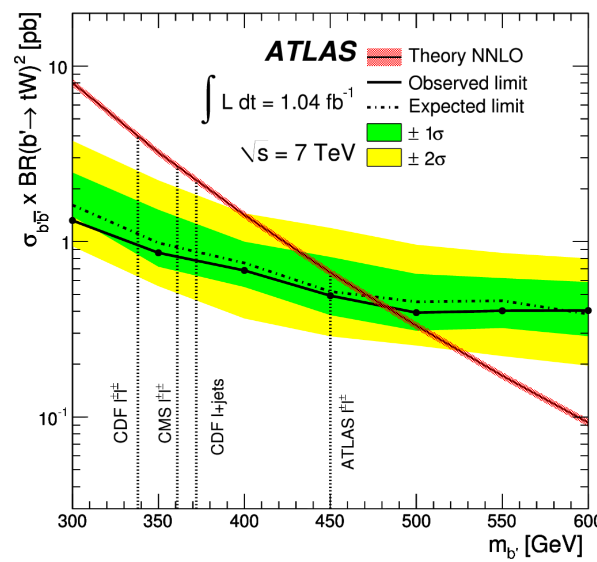
Combine two R=0.4 jets in a ΔR < 1 cone



Count the Ws (pairs with $70 < m_{jj} < 100$ GeV



Exclusion at 95 % CL m(b') < 480 GeV

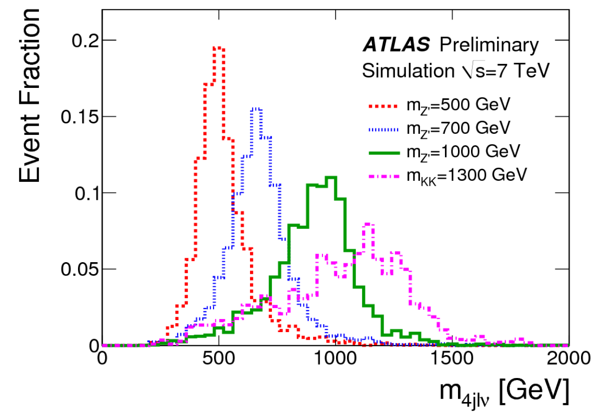


Searches with boosted top quarks: tt resonances

Fully hadronic & boosted lepton + jets in progress

Di-lepton not discussed today (1.04/fb ATLAS-CONF-2011-123)

ATLAS lepton + jets (2.04/fb ATLAS-CONF-2012-029)



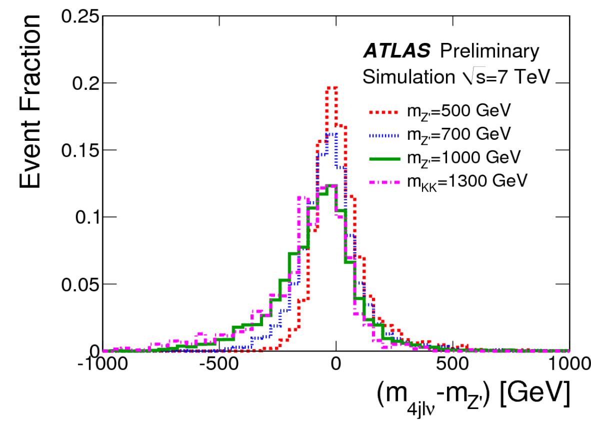
Signal Region =
Standard "lepton + jets" selection

- isolated lepton
- missing transverse momentum
- 4 jets, one b-tagged

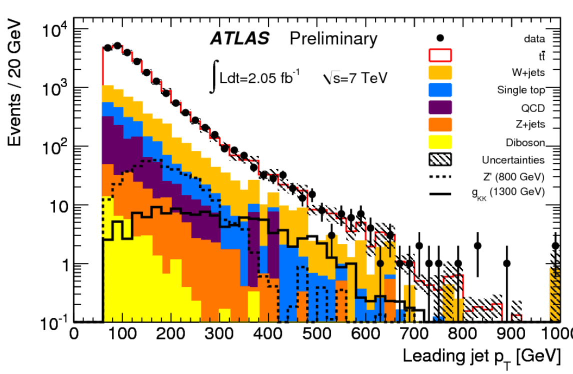
+ "fat" jet region

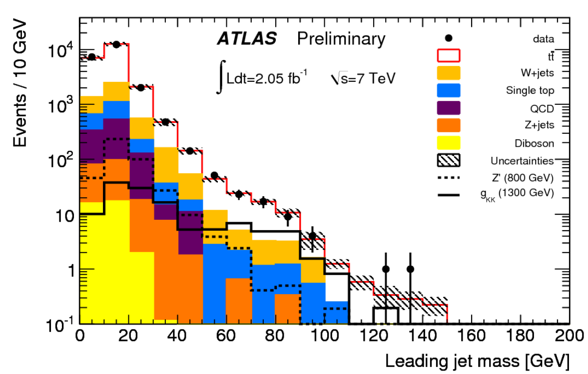
$m_j > 60$ GeV; only 3 jets are required (1% of SR)

Reconstruct m_{tt} by **combining l, ν, and 4 leading** jets with |η|<2.5 (ISR/FSR mitigation based on ΔR)



For high jet mass events **combine fat jet + nearest jet, l + nearest jet, ν**

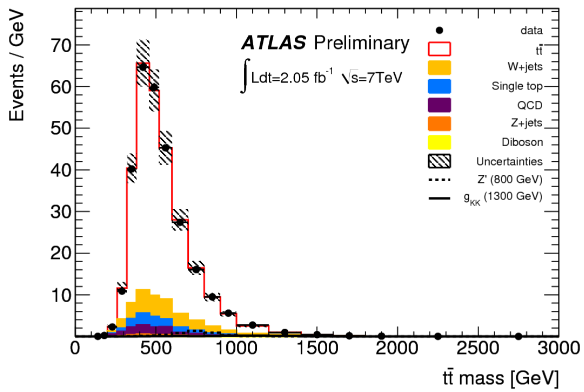




tt mass resolution

anti-k_t jets with R=0.4 well modeled, including internal structure

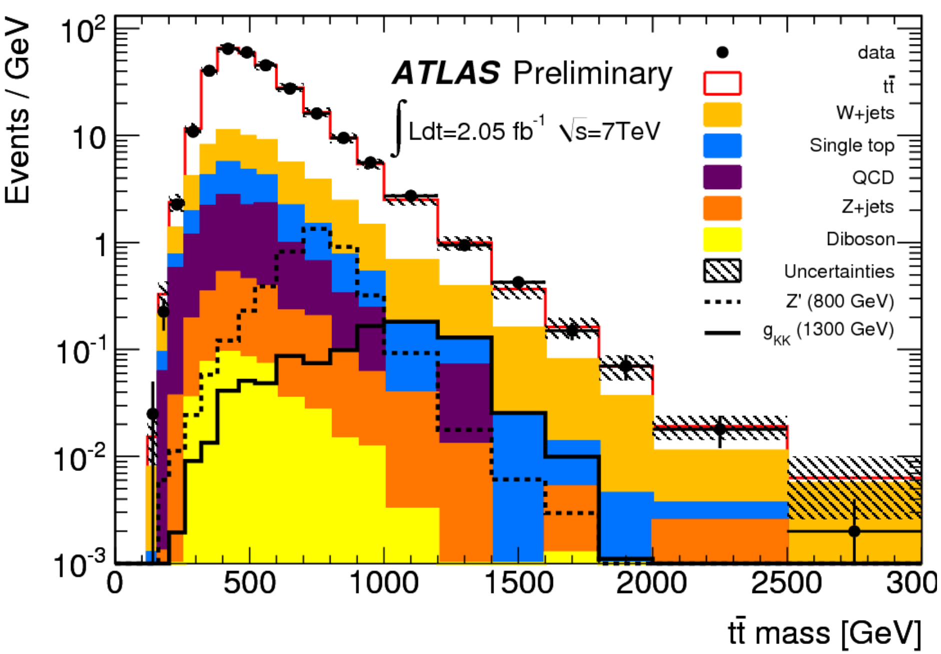
Searches with boosted top quarks: tt resonances



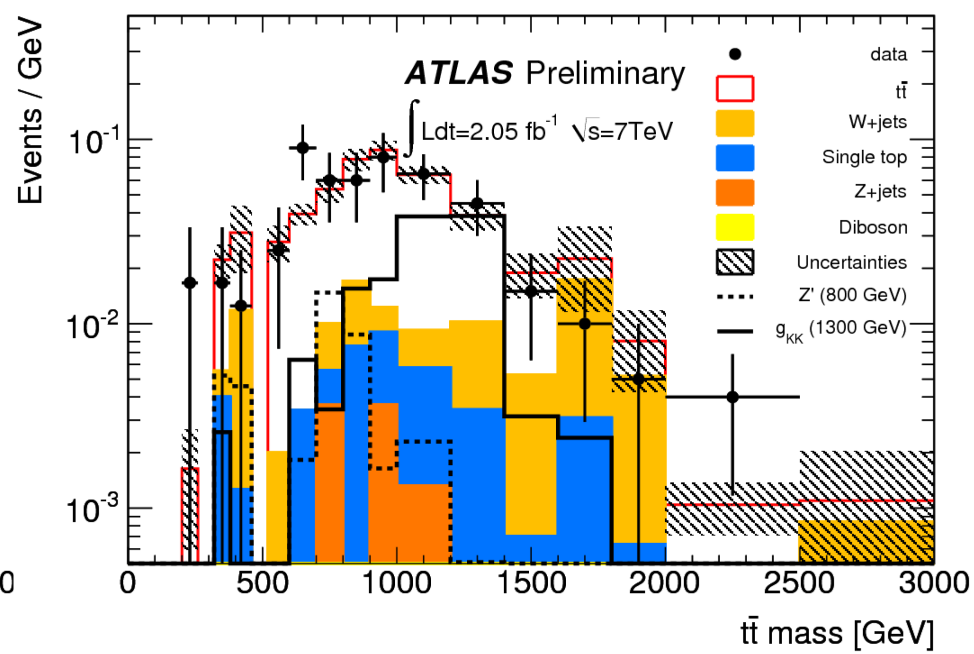
Nearly 80% of expected SM population of the Signal Region is due to tt pair production

Rejection for W+jets degraded for high mass, but still adequate. The “fat” jet region selects some of the most interesting events

Full Signal Region



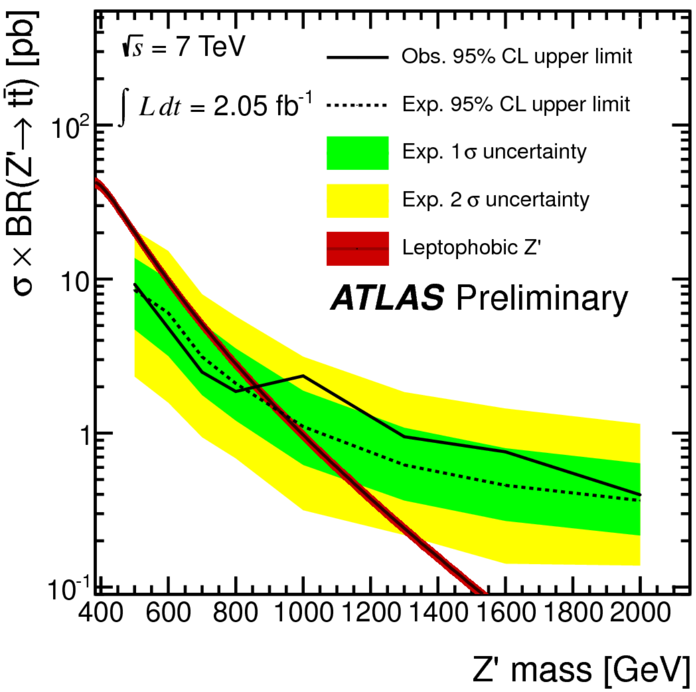
“fat” jet region

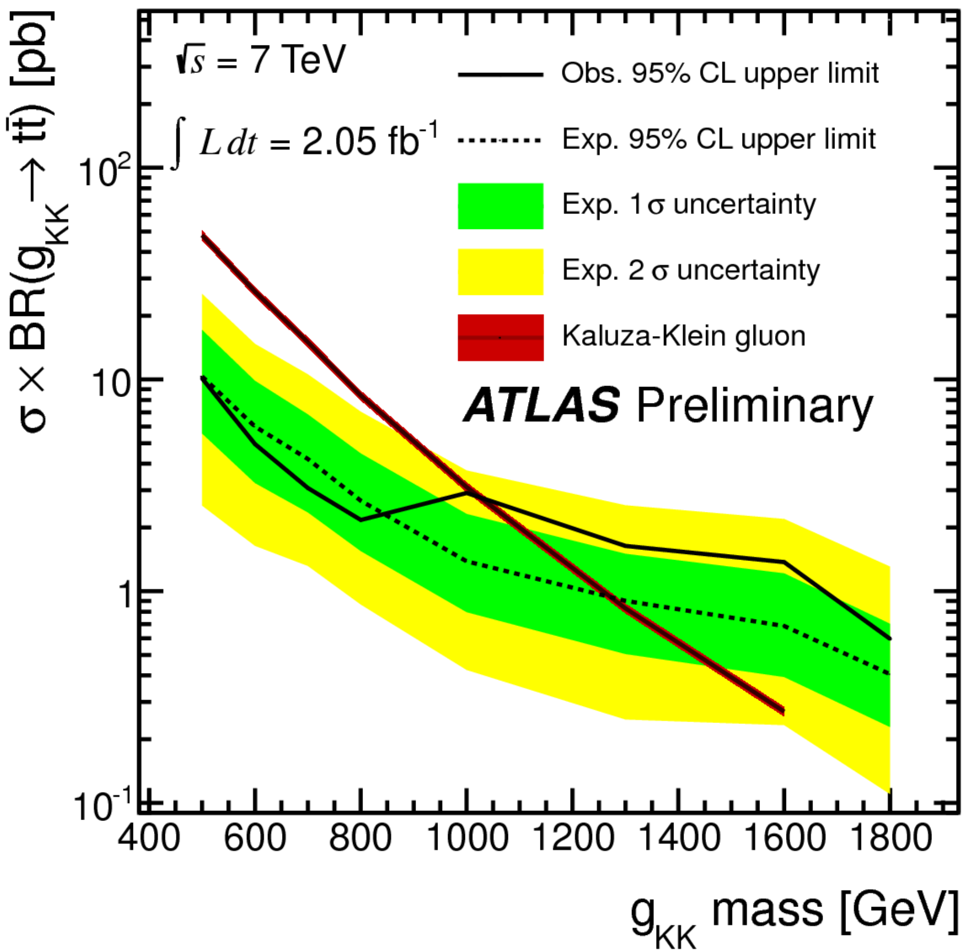


Searches with boosted top quarks: tt resonances

Rule out (at 95% C.L.) the existence of a narrow (leptophobic) Z' (in topcolor models) or a heavy broad KK excited state of the gluon

σ x BR < 9.3 pb at m = 500 GeV
σ x BR < 0.95 pb at m = 1300 GeV
Excluded mass range:
500 GeV < m(Z') < 860 GeV
500 GeV < $m(g_{KK})$ < 1025 GeV





Conclusions

The LHC takes us into the boosted regime

Boosted top quarks behave as expected, as far as we can tell

Algorithms designed specifically for the topology of boosted top quarks are expected to “boost” our physics reach

ATLAS has a fully commissioned top-tagger for hadronic decays of boosted top quarks (and is willing to use it) and is preparing more sophisticated tools

Boosted objecs without substructure: ATLAS b'b' → tt WW search

A tt resonance search that adopts some of the “boosted” ideas is sensitive to TeV-scale objects

Stay tuned!

Not on behalf of the ATLAS collaboration

Summers in Valencia are hot, but not unbearable. Throughout July and August the average daily temperature is about 30 ºC (86 F), accompanied by mild humidity.