Jet Substructure

Nicolas Gutierrez

Boosted objects: phenomenology

The potential of this paradigm has been amply demonstrated:

✓ **Boosted W**

➔ Vector boson scattering, Butterworth, Cox and Forshaw, Phys. Rev. D65:096014 (2002)

"A new method for identifying hadronically decaying W bosons is introduced, which we expect to be useful more generally in the identification of hadronically decaying massive particles which have energy large compared to their mass"

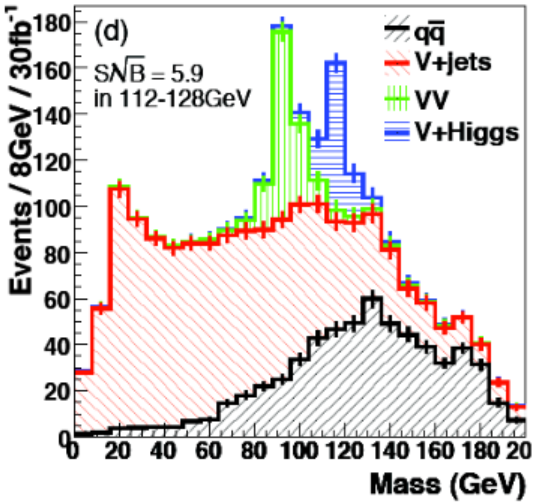
➔ See also paper by Cui, Han, Schwartz paper, arXiv:1012.2077[hep-ph]

✓ **Boosted Higgs, in particular light H → bb**

- WH, Butterworth, Davison, Rubin, Salam, Phys. Rev. Lett. 100:242001 (2008)

" We conclude that subjet techniques have the potential to transform the high-pT WH,ZH (H → bb) channel into one of the best channels for discovery of a low mass Standard Model Higgs at the LHC"

- ZH, Soper, Spannowsksy, JHEP 1008:029 (2010)
- ttH, Plehn, Salam, Spannowsky, Phys. Rev. Lett. 104 (2010)



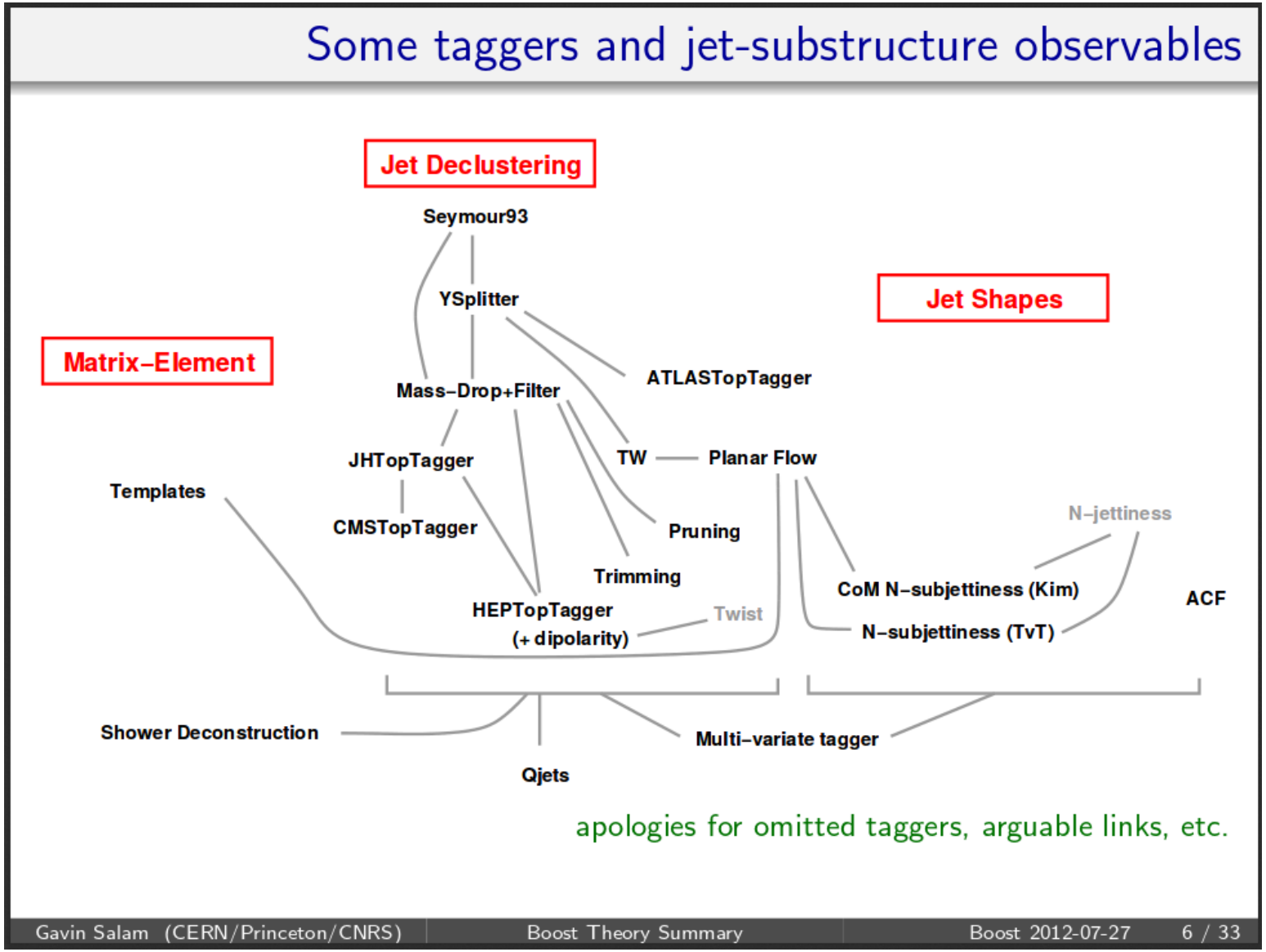
Full-simulation by experiments:

Boosted W: CERN-OPEN-2008-020, arXiv:0901:0512 [hep-ex], pages 262 and pages 1769)

Boosted Higgs: ATL-PHYS-PUB-2009-088, CERN-THESIS-2010-027

BOOST2011, Princeton, May 2011

A New Hope — The Bang — Consolidation



A New Hope — The Bang — Consolidation

applications of substructure

Aug. 22, 2014 44

Nikos | Badder | Bonnie | Christoph | Kevin
Danielo | Andreas | Raffaele | Trisha

Many new analysis arriving in the past year!
Those discussed this year…

VLQs in T or $Y^{4/3}$ → Wb (pair production)
T' → tH (pair production), all-hadronic
W' → tb
$T^{5/3}$ → Wt (pair production)
T' → tH, tZ, Wb (pair production)
b' → bH (pair production)

ttbar differential cross-section
Zbb
inclusive boosted W/Z (dijets)

VV → qq qq
WV → lν qq
ZV → ll qq

mono-W/Z and invisible Higgs

VH(→ bb) (SM)
HH → bbbb
HH → bbγγ

ttbar resonances (all-hadronic)
ttbar resonances (semi-leptonic)

direct stop pair search (0L and 1L)

+ many unfolded measurements!

Will focus on the boosted regime and what methods are being used (based on a biased/low stats sampling of the questions asked to the speakers)

Nhan Tran. Boost2014

A New Hope — The Bang — Consolidation

This talk

Focus on contributions to the consolidation of jet substructure

- Top tagging performance

  A full information observable

- Application of jet-substructure

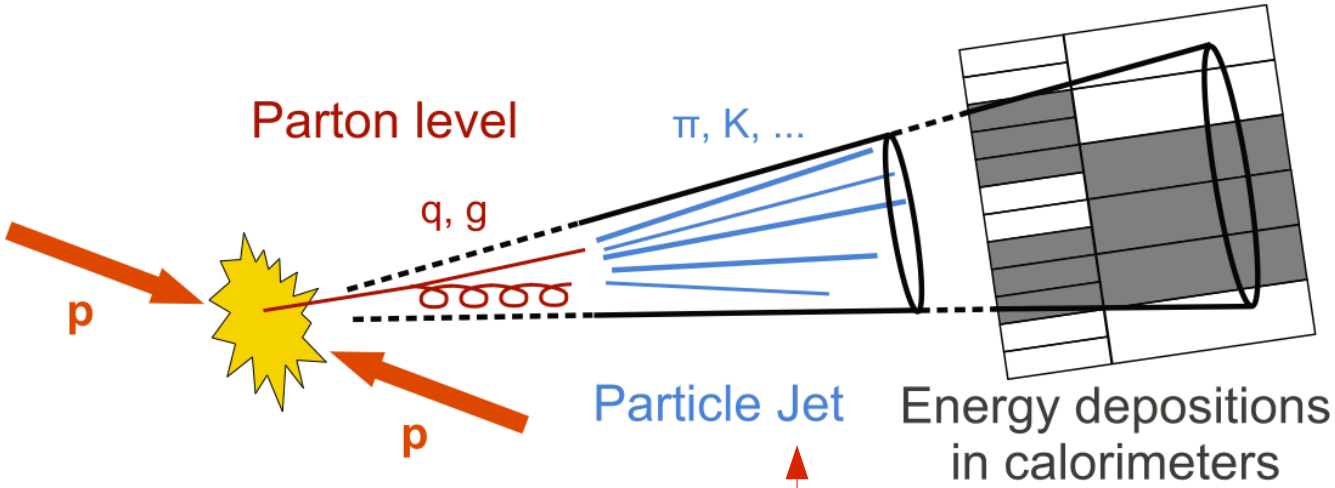
  Search for new physics

- Taken from:

  ATLAS-CONF-2014-003

  NG thesis

Basics of jet reconstruction

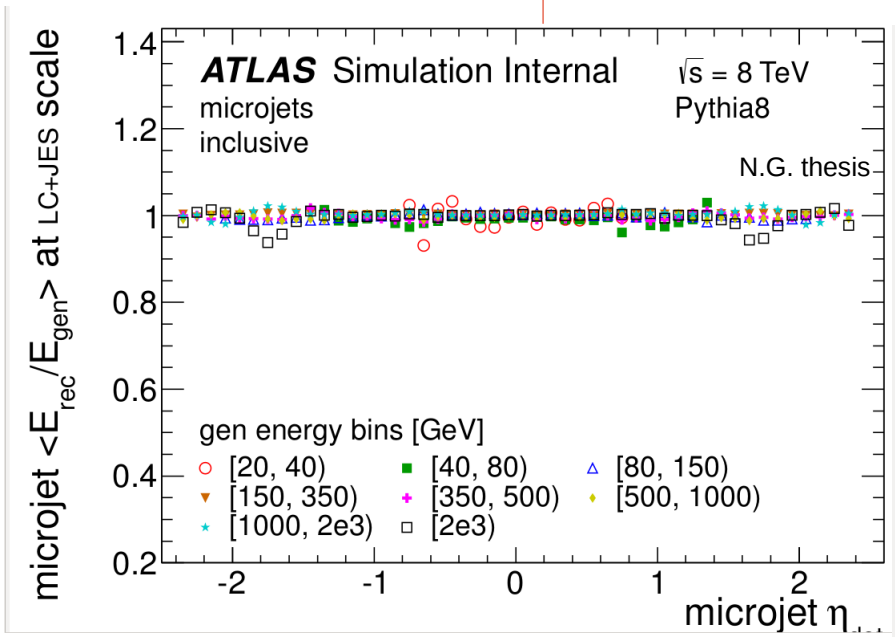


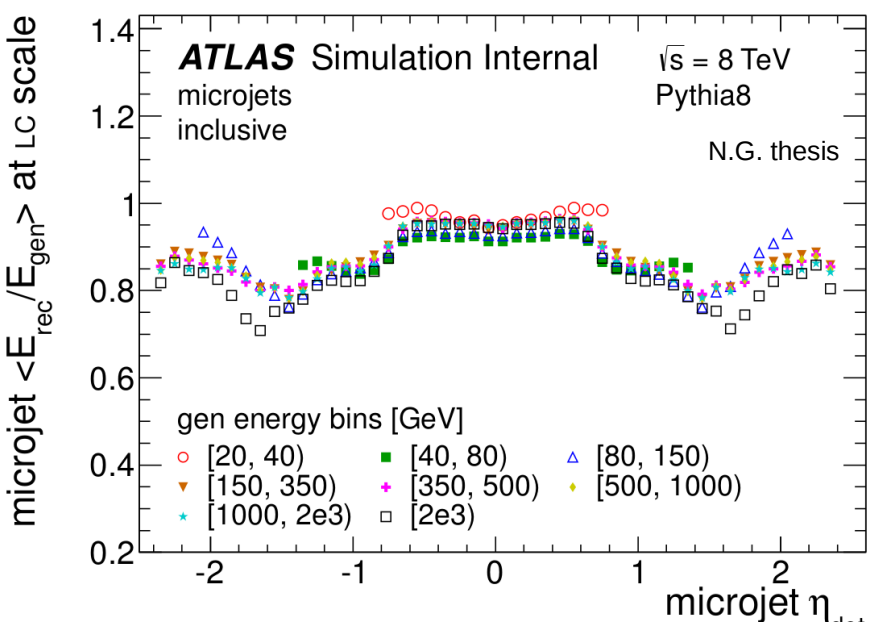
* Finite granularity

* Understanding the detector is the key to realise new ideas in data

Correct for detector effects

A lot more is needed

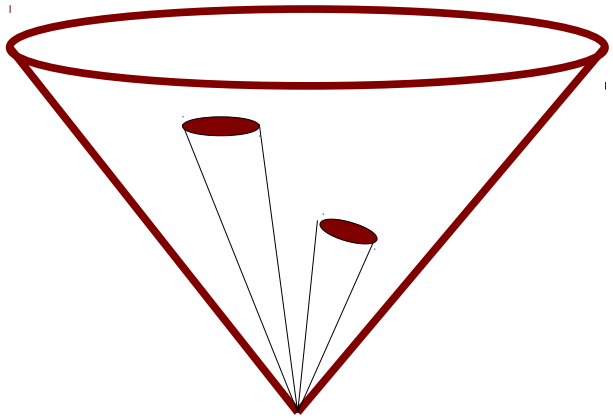




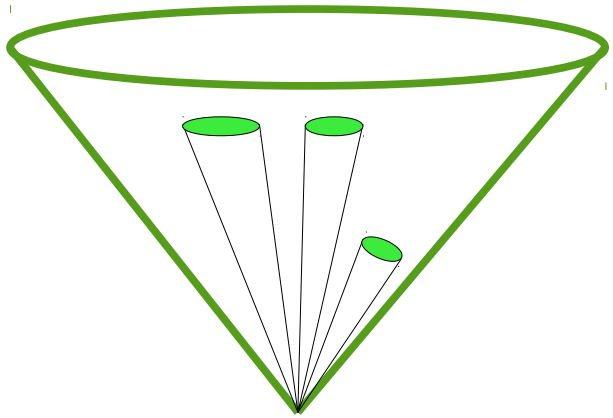
* Account for data to simulation differences
* Uncertainties estimation

An example of jet substructure

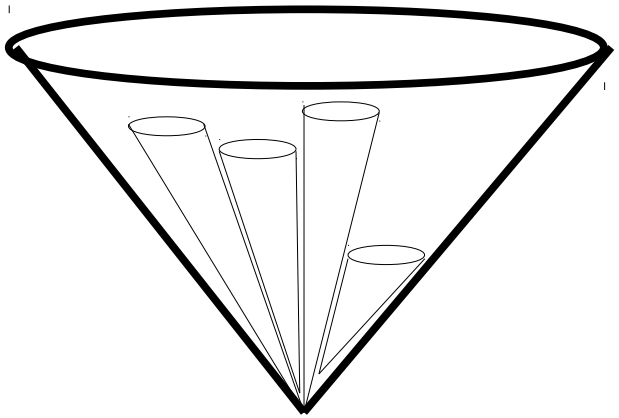
low fatjet mass
low **subjet** multiplicity
hard core + soft **subjets**



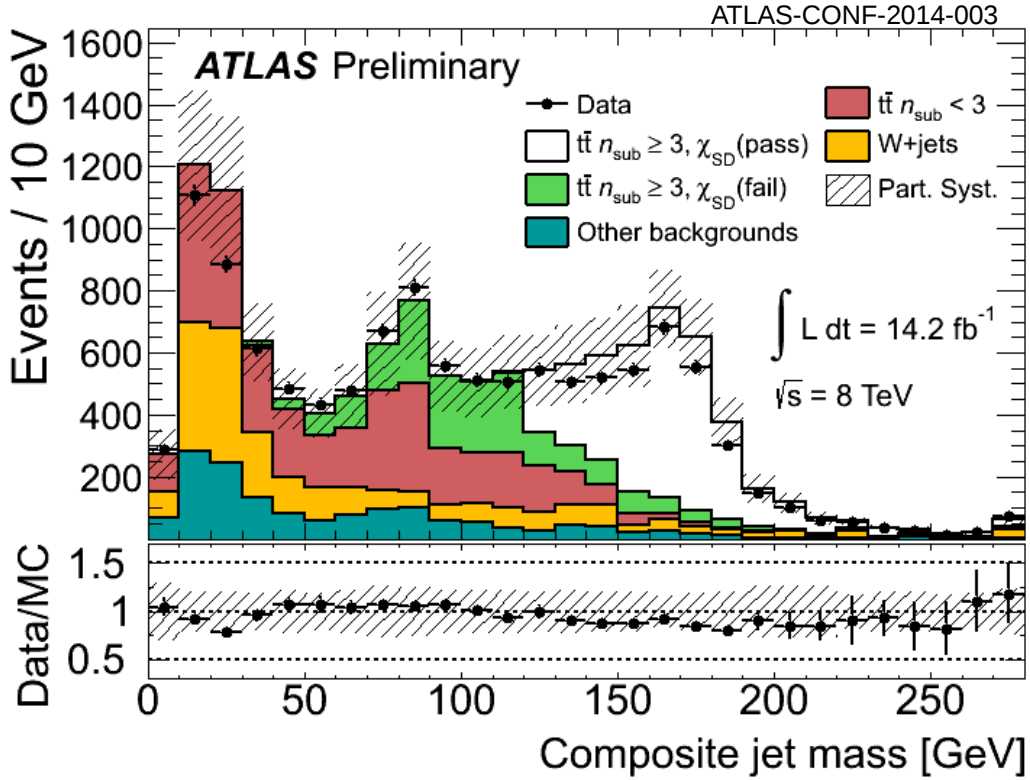
fatjet mass ≥ W-boson
two hard **subjets**
partially contained top-quark



fatjet mass ≥ top-quark
three hard **subjets**
fully contained top-quark

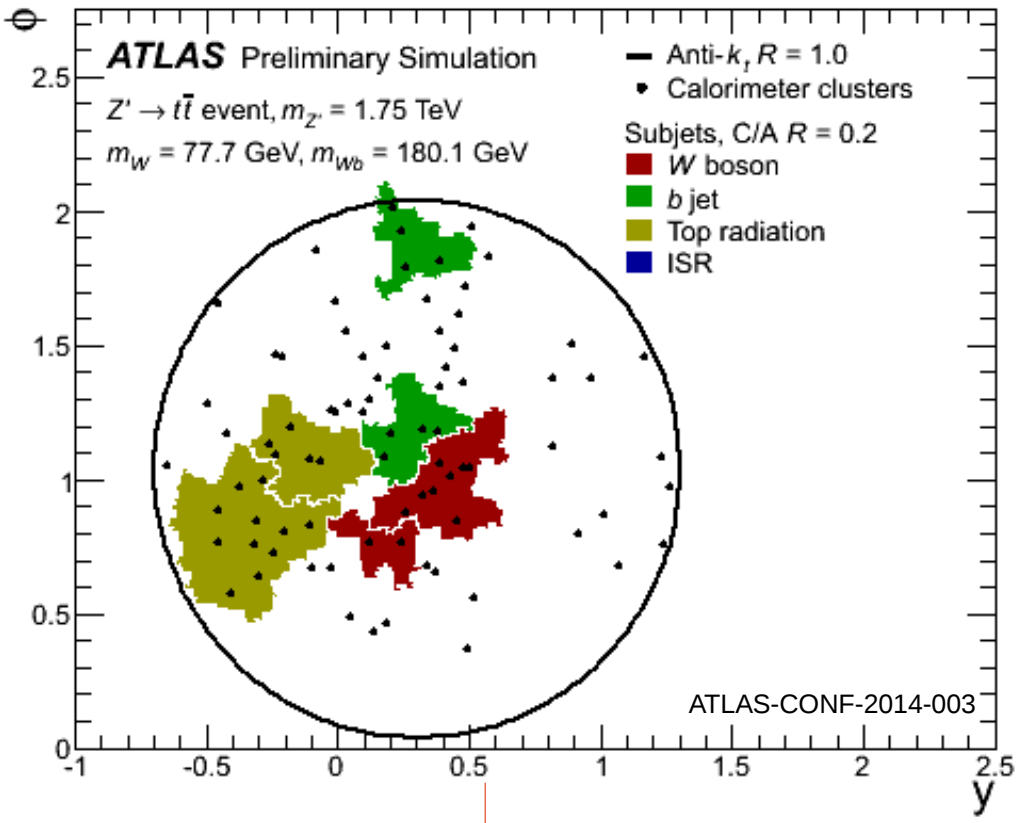


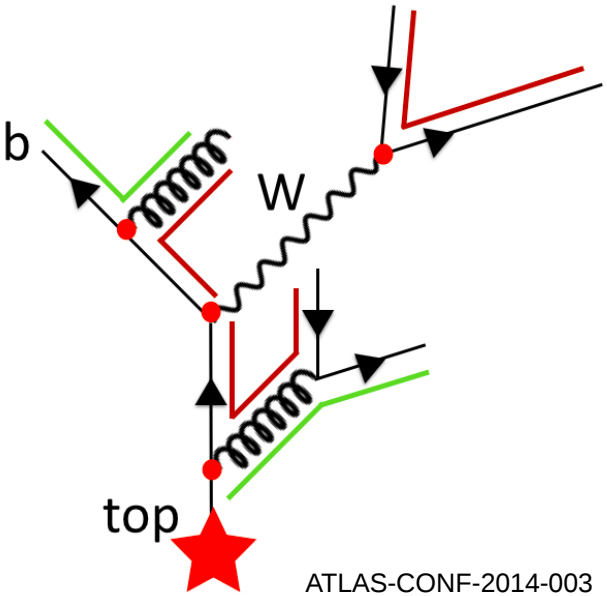
ATLAS-CONF-2014-003



Shower deconstruction

* all possible combinations of subjets are considered
* subjets are combined according to signal (top) and background (QCD) hypothesis
* each combination (shower history) is assigned a weight
* weight uses ME and Sudakov factors
* observable χ_{SD} given by the ratio of the total signal to background probabilities

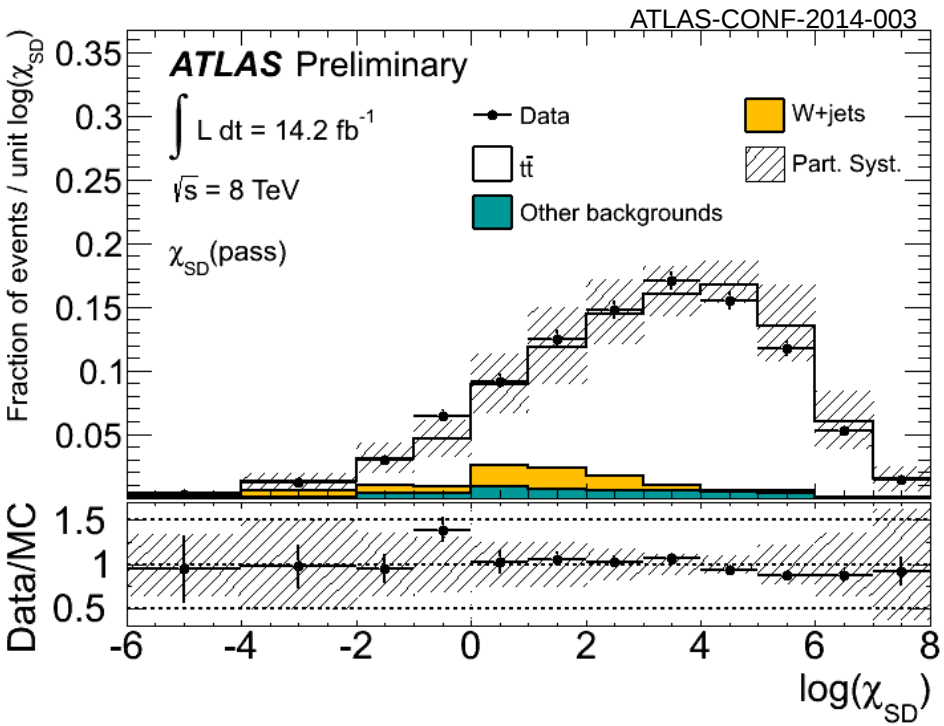


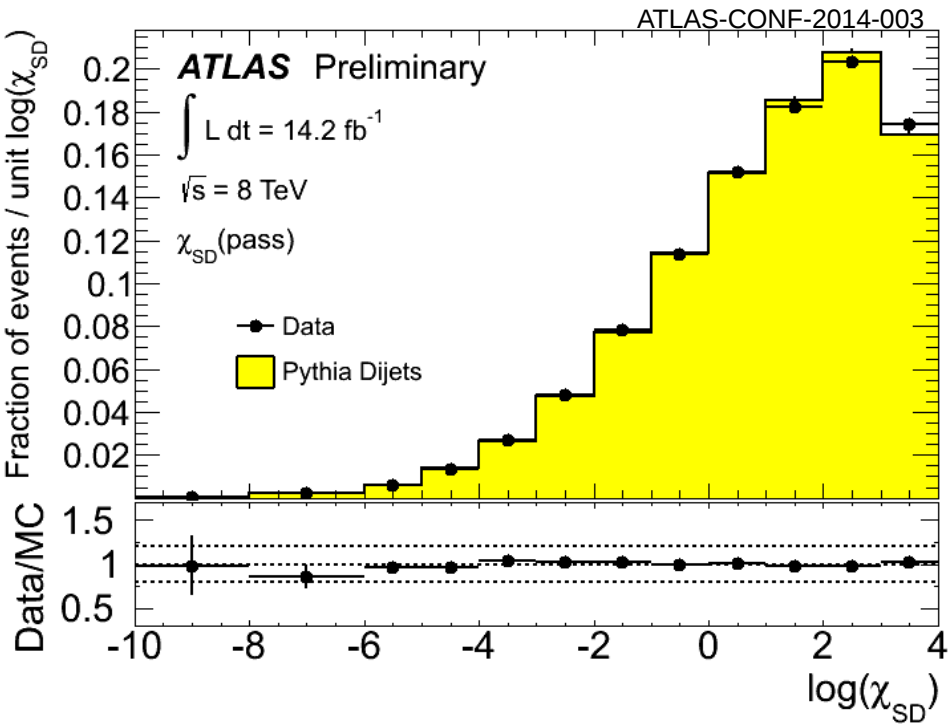


many more combinations are possible

Shower deconstruction

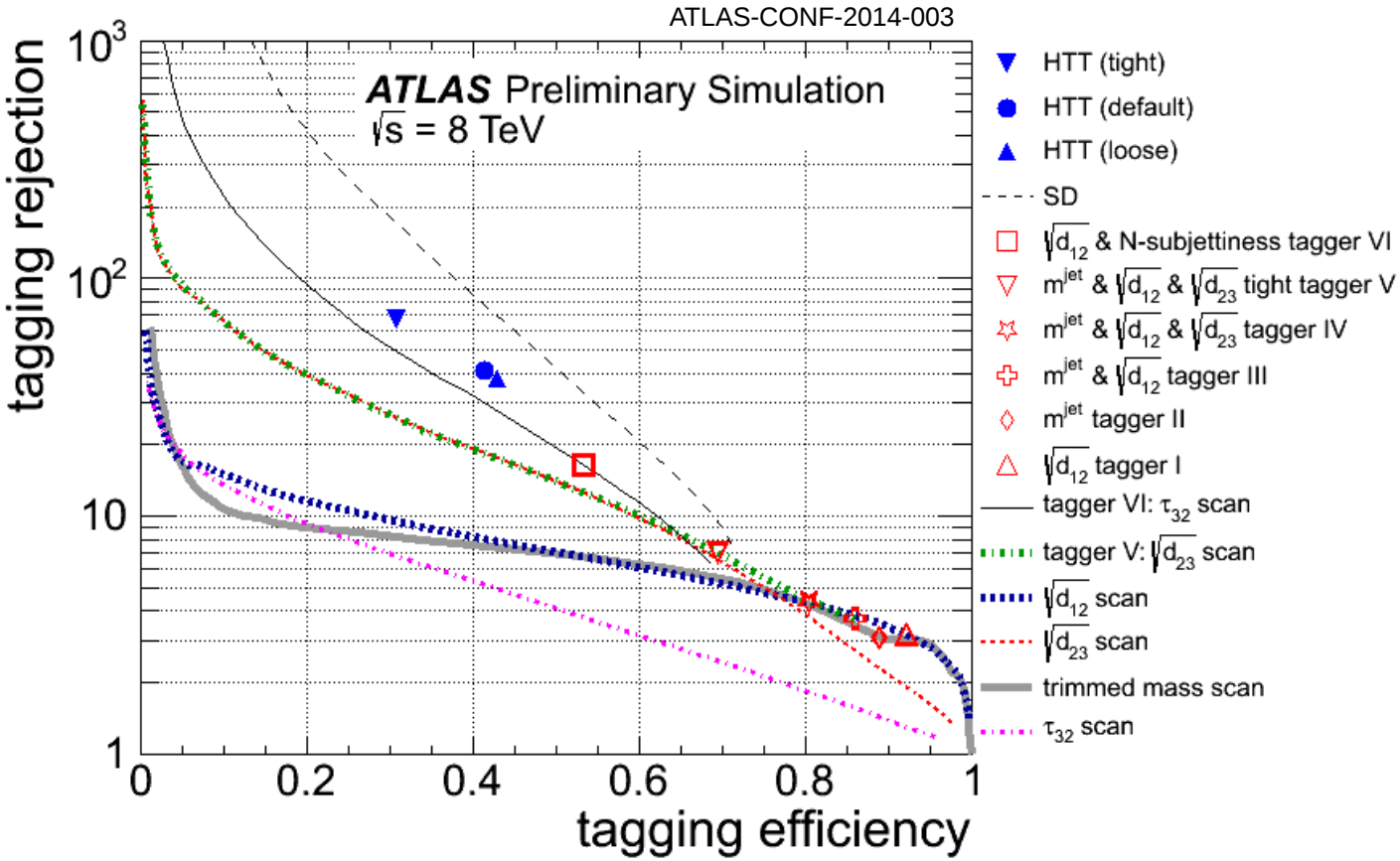
* still feasible after detector effects
* good description of the observable by the simulation





Shower deconstruction

* still feasible after detector effects
* good description of the observable by the simulation
* best background rejection over a wide range of signal efficiency
* ideal for final states with huge QCD backgrounds



Single production of vector-like quarks

* larger cross section than pair production for high masses
* current limits reach 700 GeV
* the objective is to extend the reach to the TeV scale
* coupling to SM model dependent, two interpretations
  - **A handbook of vector-like quarks: mixing and single production**
    J.A. Aguilar-Saavedra, R. Benbrik, S. Heinemeyer, M. Perez-Victoria
  - **A First Top Partner Hunter's Guide**
    A. De Simone, O. Matsedonskyi, R. Rattazzi, A. Wulzer

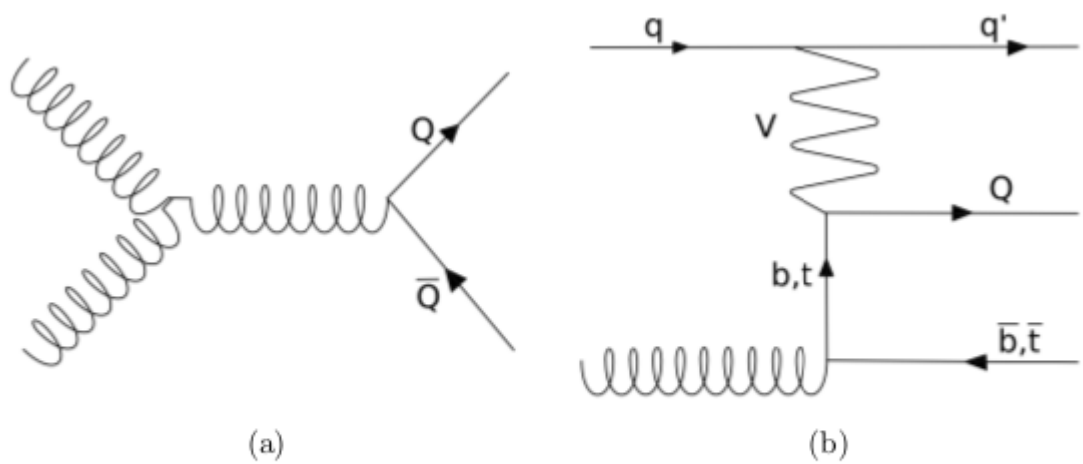


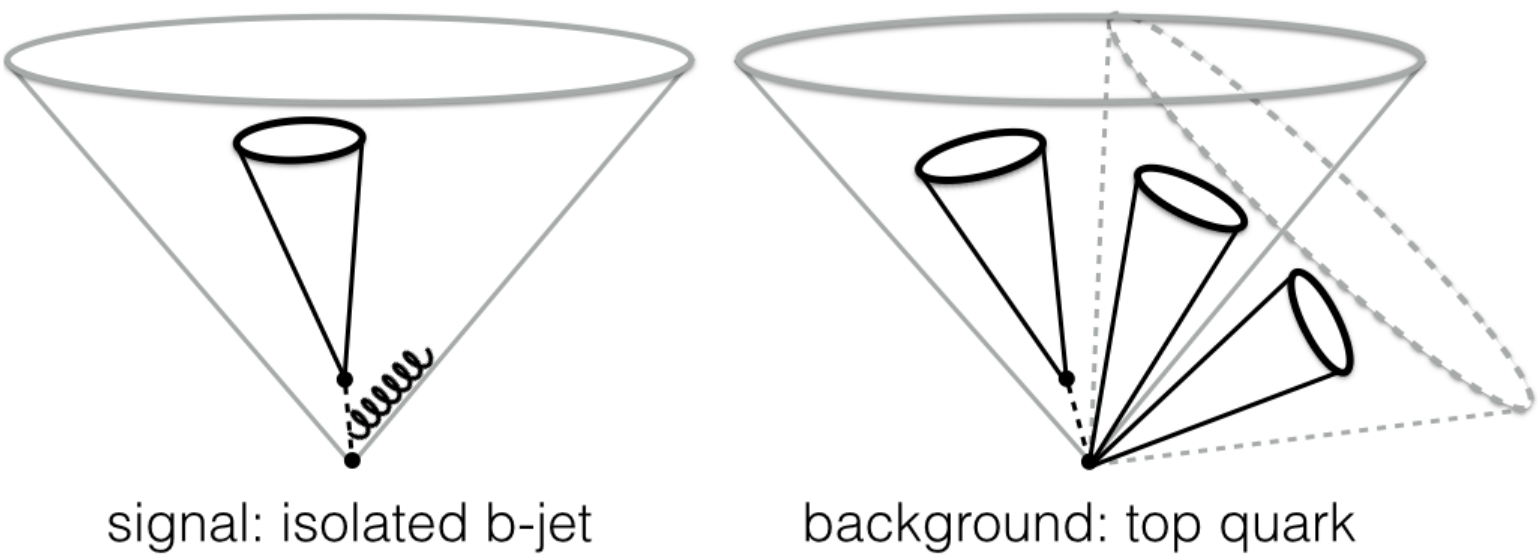
Figure 1.5: A representative diagram illustrating the production of pairs of (a) and a single (b) VLQ.

Single production of vector-like quarks

* vector-like top (T) → Wb → $l\nu$b
* heavy T:
  - high-pT W and b
  - W and b produced back to back
  - isolated b-jet
  - using the large-R jet mass as a proxy to the isolation of a very high-pT b-jet

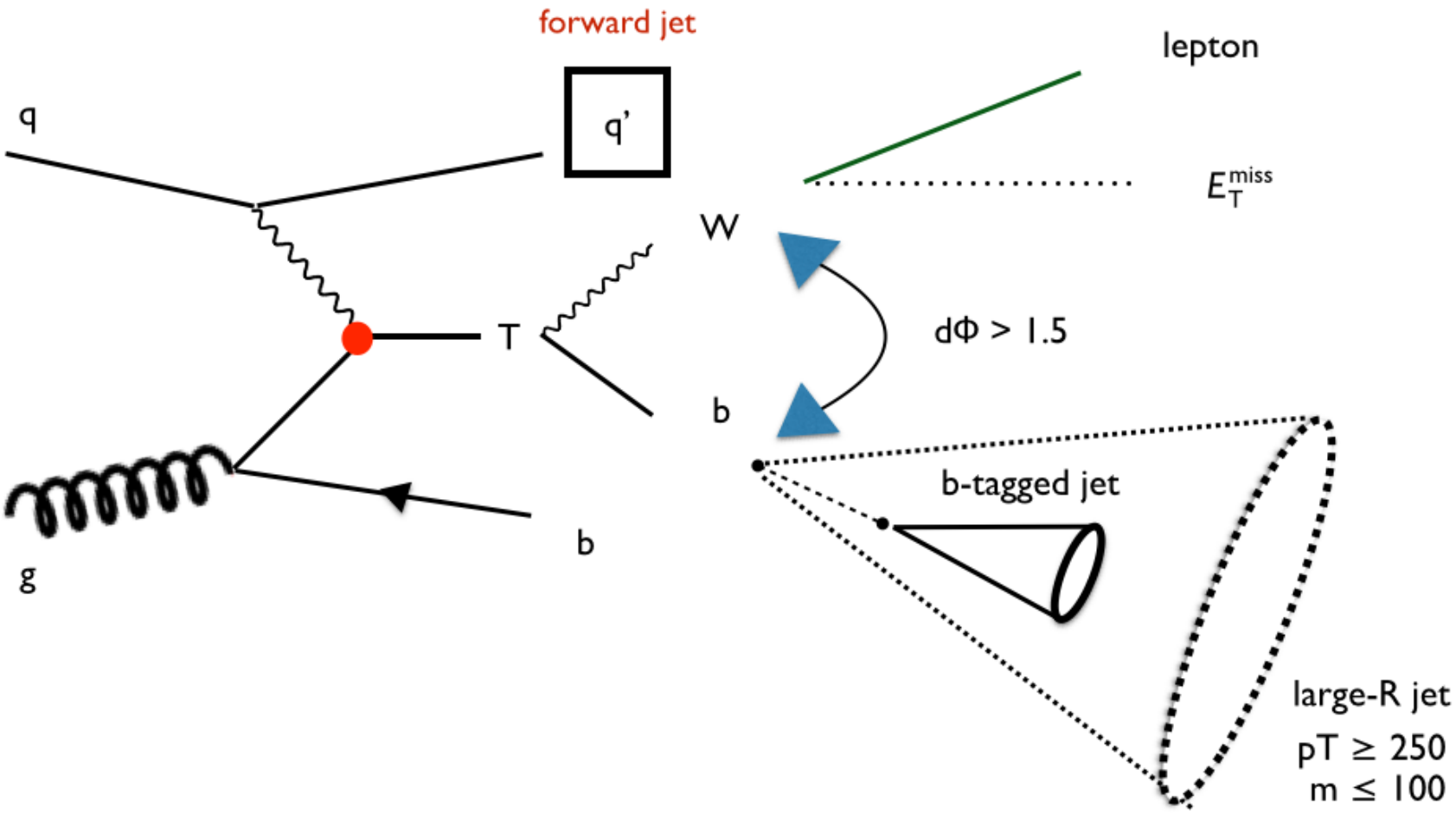
Reconstructing singly produced top partners in decays to Wb

N.G., J. Ferrando, D. Kar, M. Spannowsky



Single production of vector-like quarks

* vector-like top (T) → Wb → $l\nu$b
* heavy T:
  - the final state



Single production of vector-like quarks

* vector-like top (T) → Wb → $l\nu$b
* still feasible after detector effects

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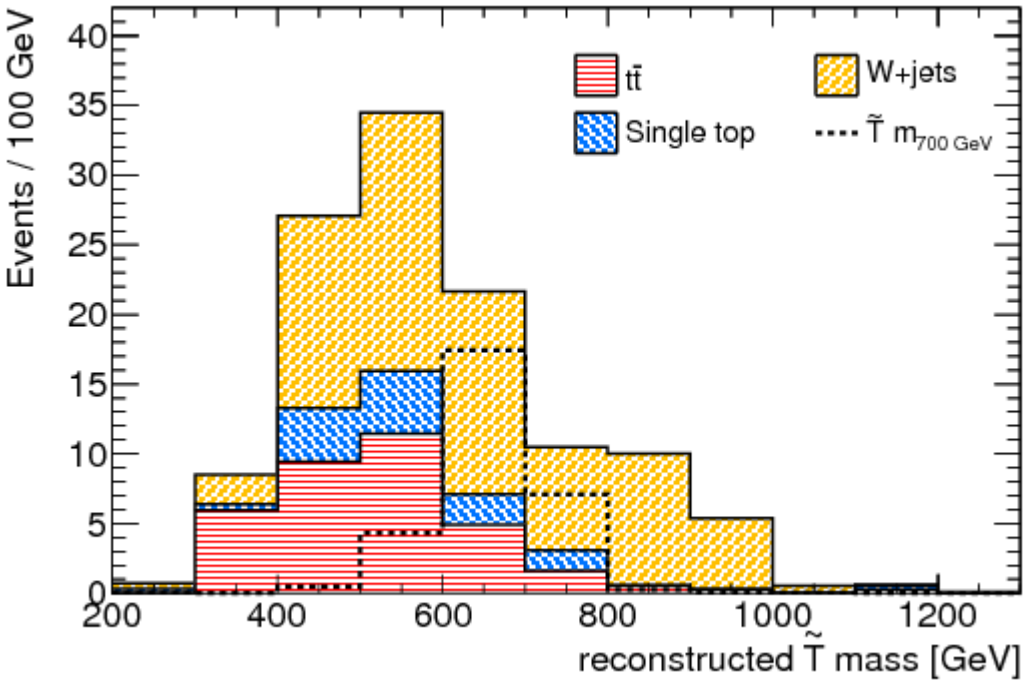
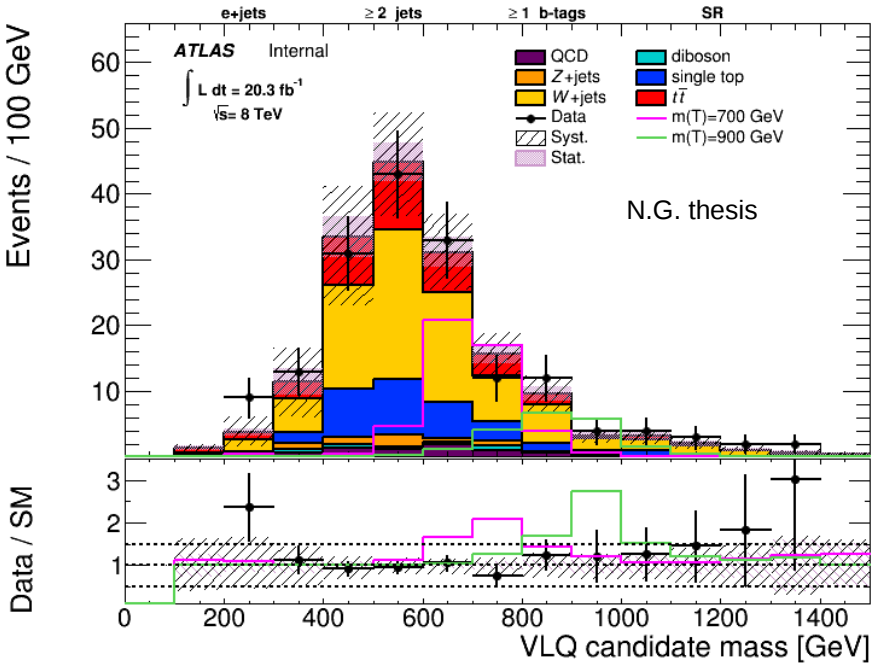
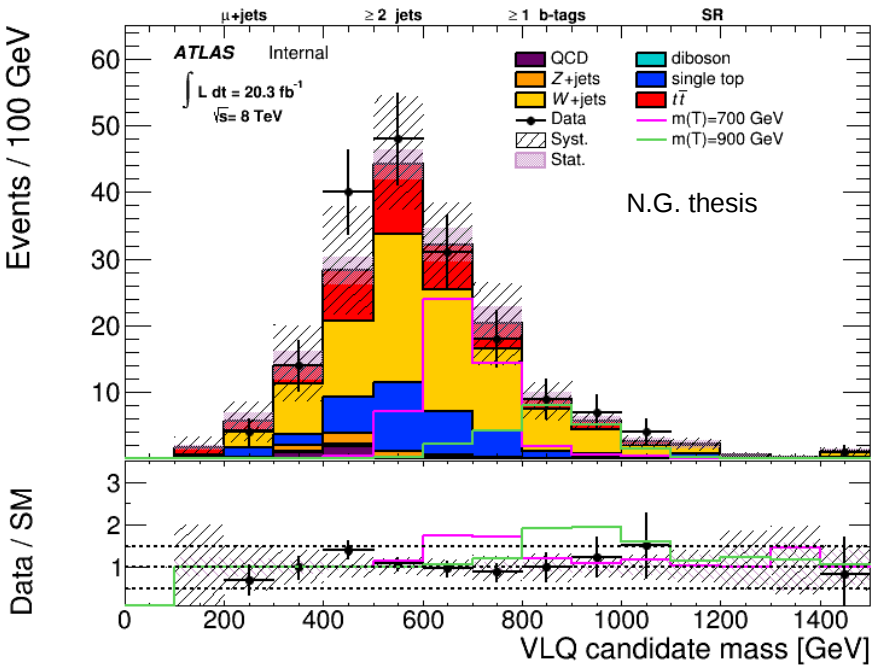
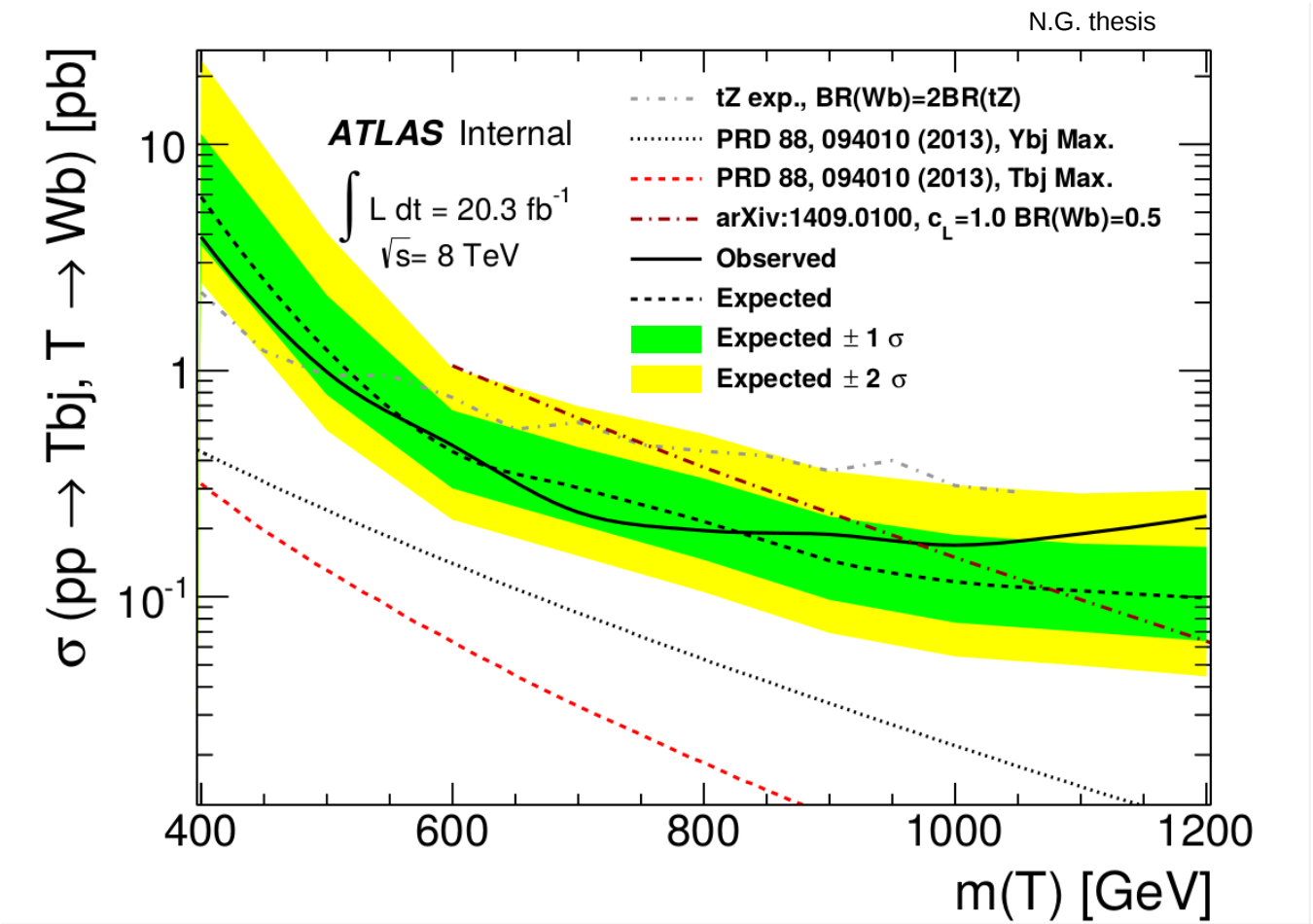






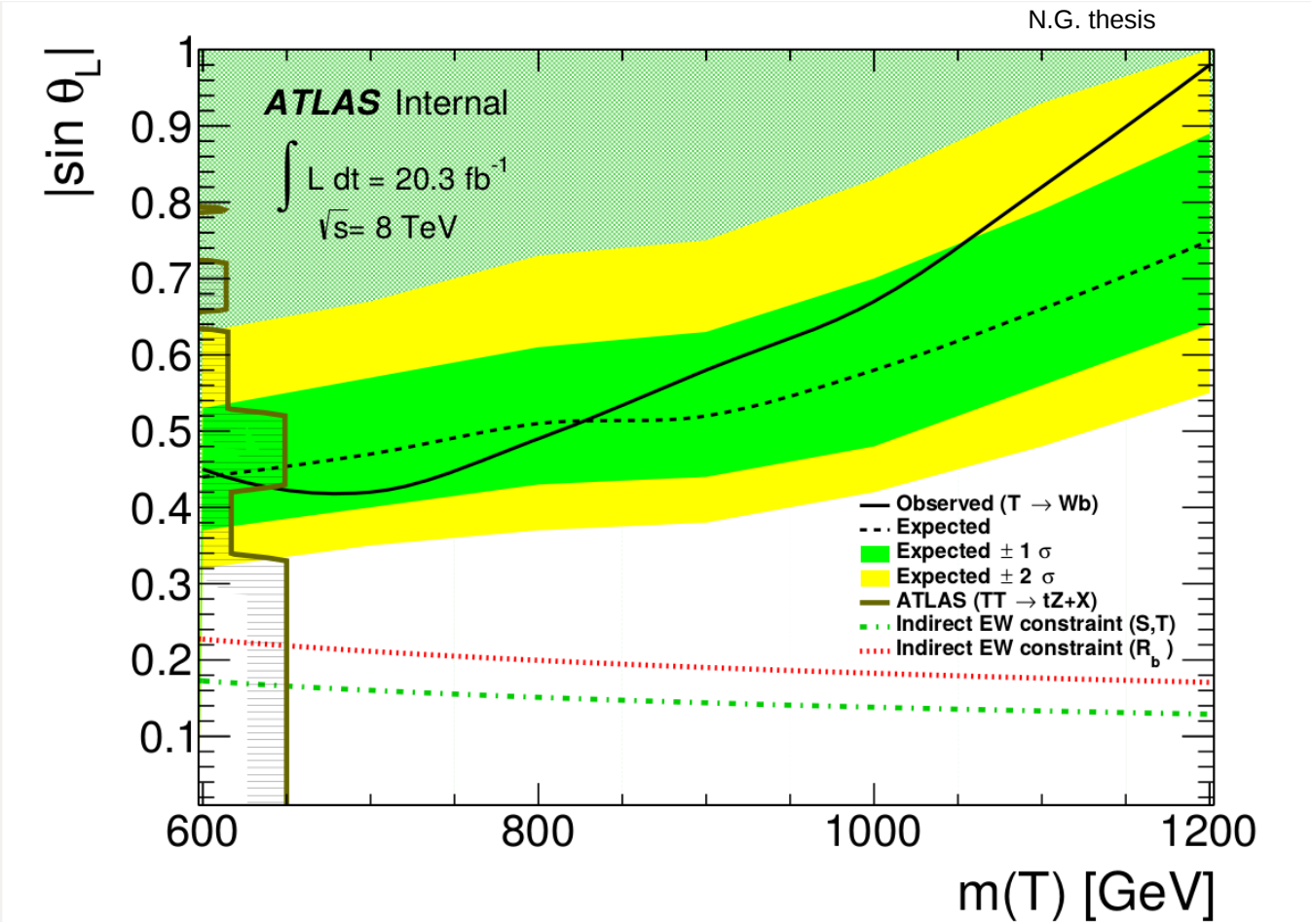
Single production of vector-like quarks

* vector-like top (T) → Wb → $l\nu$b
* statistical analysis using a likelihood fit of nuisance parameters and signal strength
* TeV scale on sight



Single production of vector-like quarks

* vector-like top (T) → Wb → $l\nu$b
* interpretation on the mixing versus mass space (J.A. Aguilar-Saavedra et. all)



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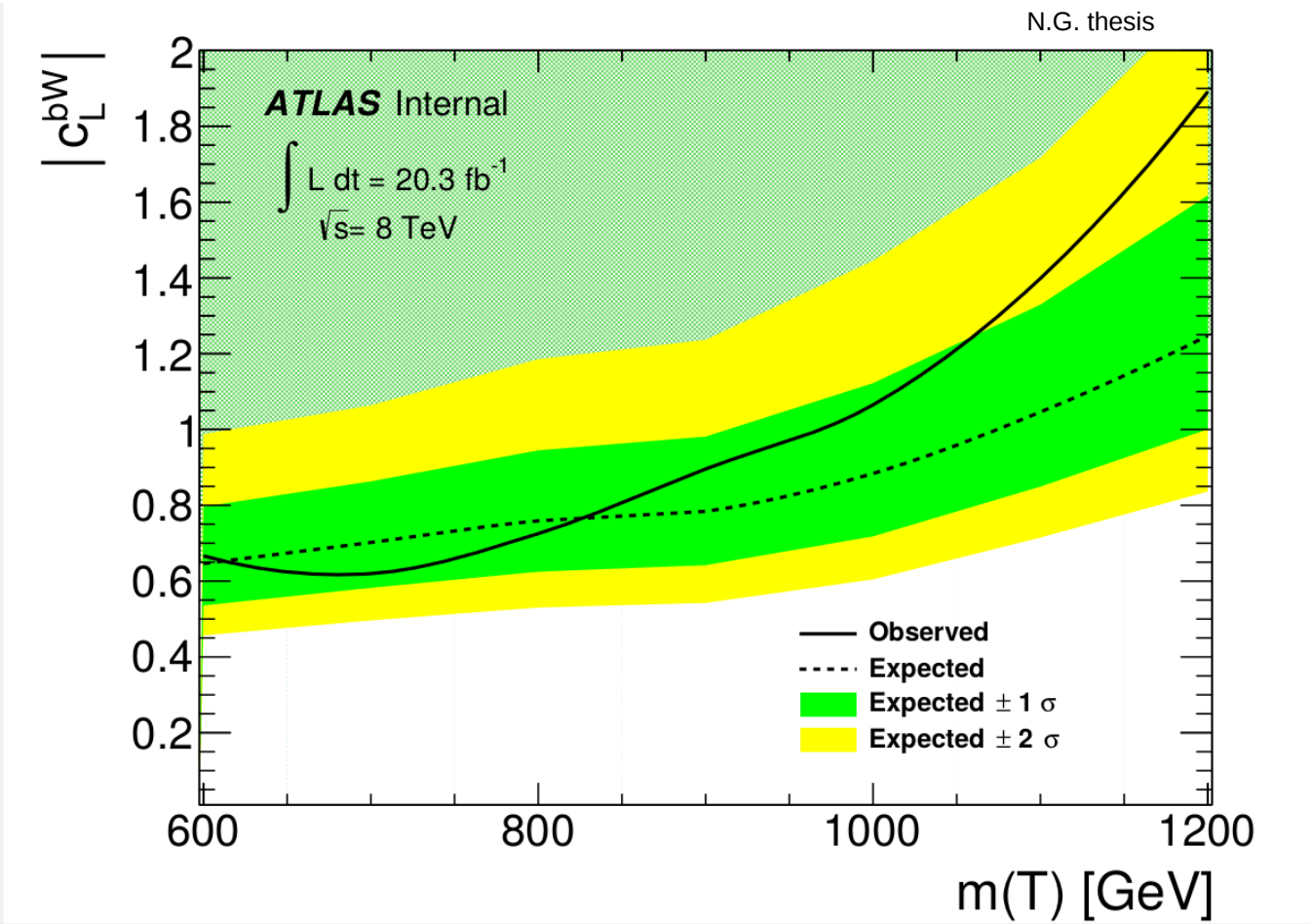

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Single production of vector-like quarks

* vector-like top (T) $\rightarrow$ Wb $\rightarrow$ $l\nu$b
* still feasible after detector effects
* TeV scale on sight
* interpretation on the mixing versus mass space (J.A. Aguilar-Saavedra et. all)
* interpretation on the coupling versus mass space (A. De Simone et. all)

Looking ahead

* expertise of HiggsTools members on Jet Substructure
* maximise the potential these tools have for an observation of H$\rightarrow$bbar