Searches with top quarks in ATLAS

Vector-like quarks and resonances

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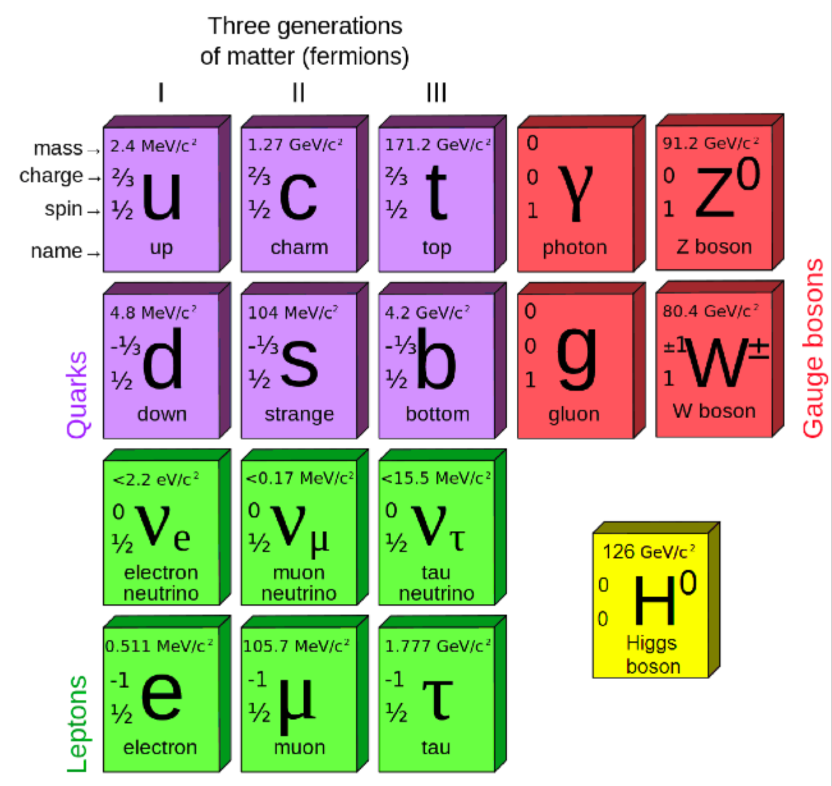
Standard Model

Where we stand …

- Successfull theory: describes **elementary particles** & **interactions**
- "Last" piece discovered in 2012: **Higgs boson**



Standard Model

Where we stand …

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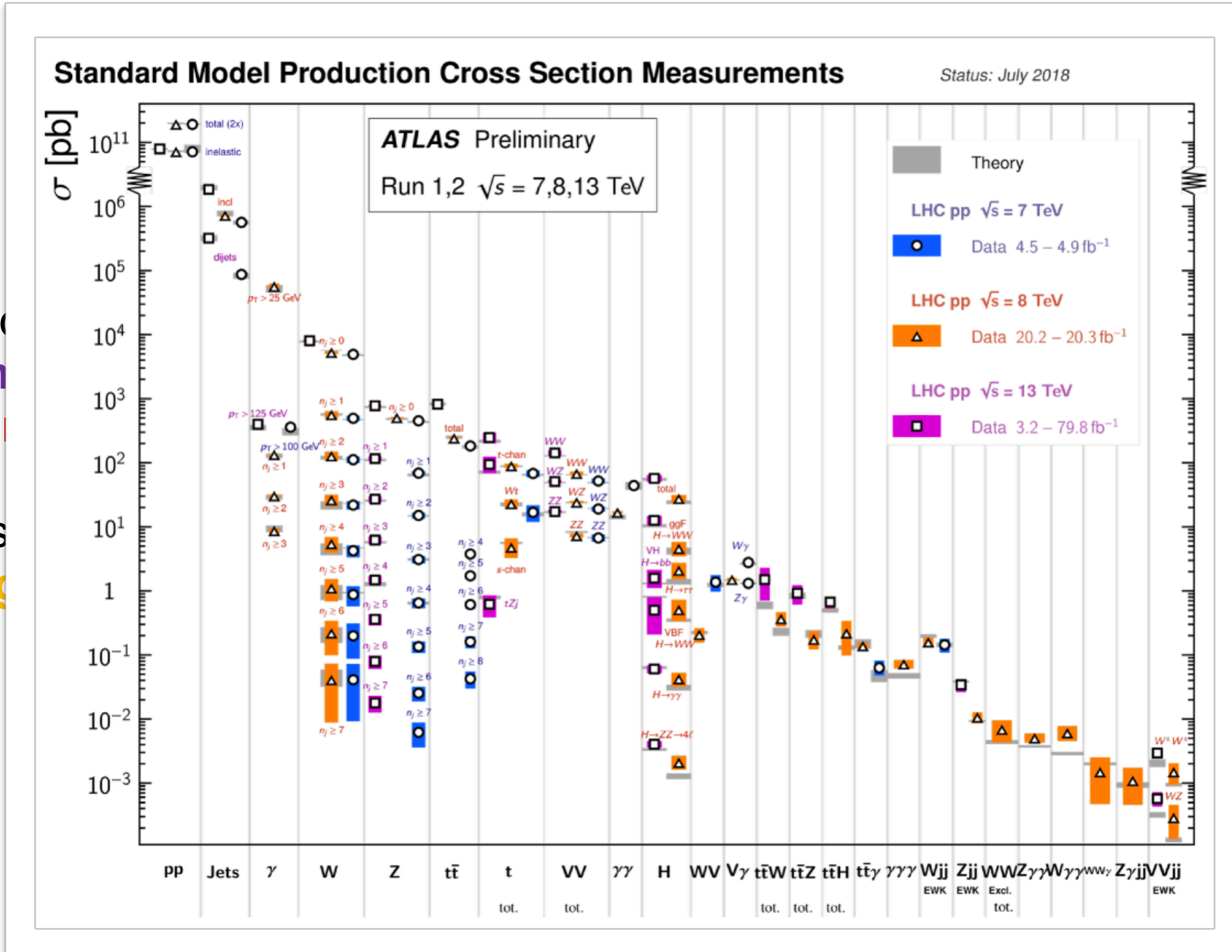
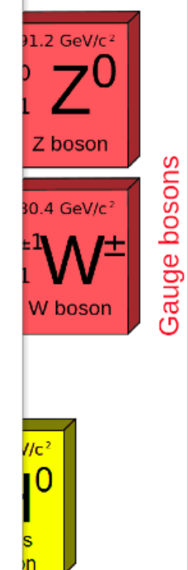




Standard Model

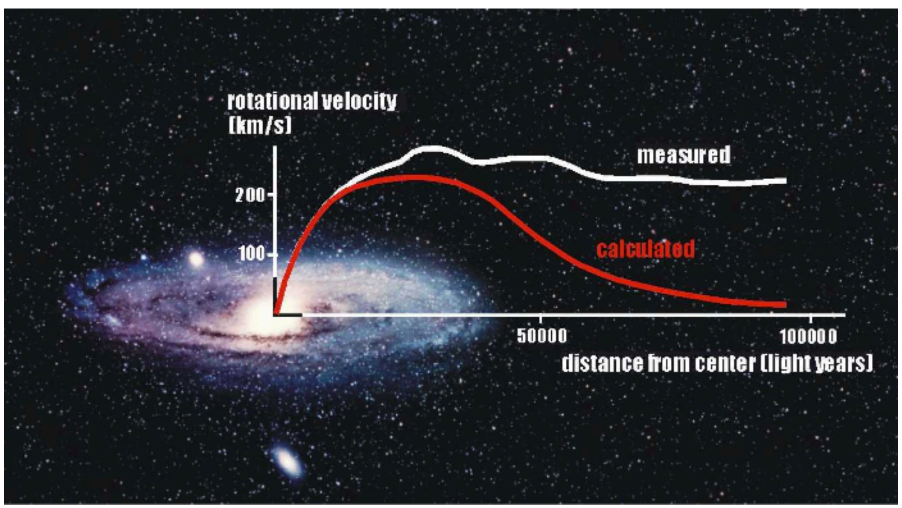
But …

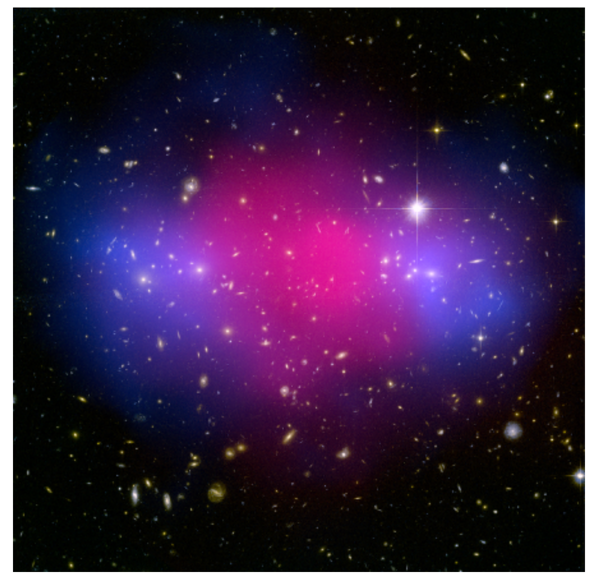
- **Limitations / unnatural observations**

Standard Model

But …

- Limitations / unnatural observations
  - Dark Matter: not described in Standard Model

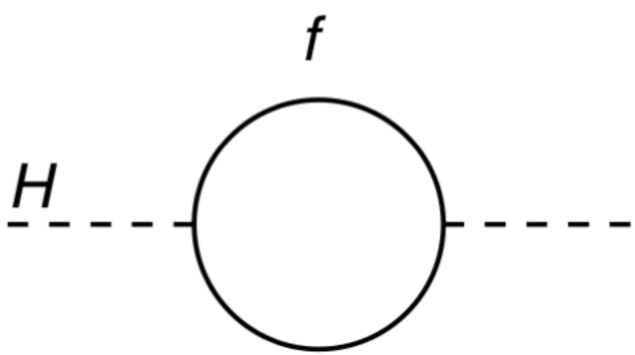


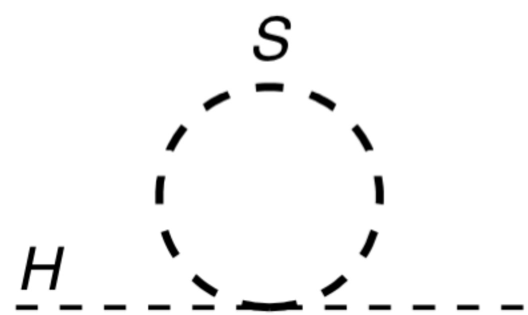


Standard Model

But …

- Limitations / unnatural observations
    - Dark Matter: not described in Standard Model
    - Higgs boson mass: naturally expected to be heavier

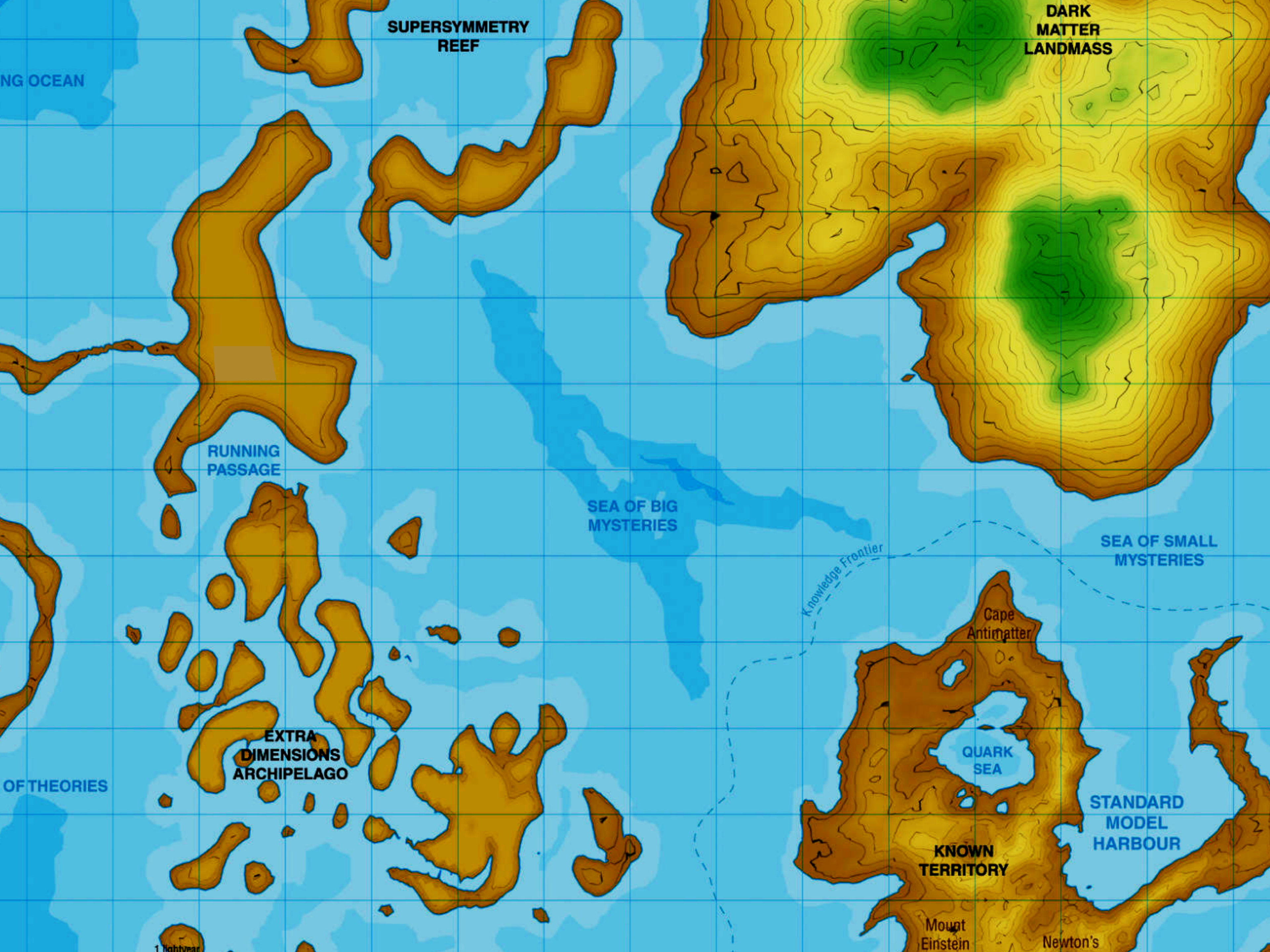




Standard Model

But …

- **Limitations** / **unnatural observations**
    - **Dark Matter**: not described in Standard Model
    - **Higgs boson mass**: naturally expected to be heavier
    - etc …


NG OCEAN
SUPERSYMMETRY REEF
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RUNNING PASSAGE
SEA OF BIG MYSTERIES
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Cape Antimatter
QUARK SEA
EXTRA DIMENSIONS ARCHIPELAGO
OF THEORIES
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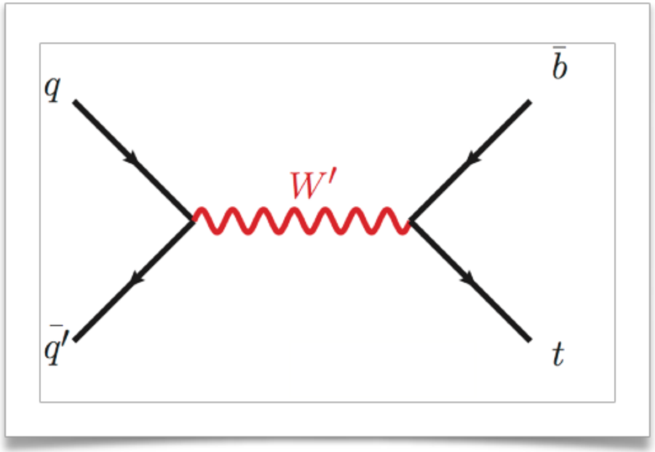
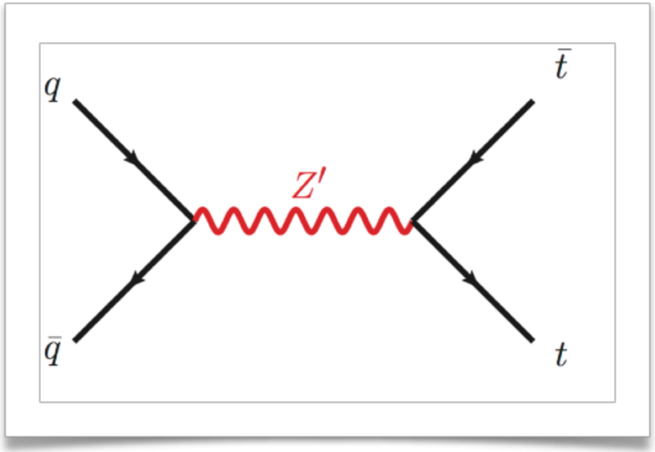
Mount Einstein
Newton's
1 lightyear

Beyond the Standard Model

Where we go …

- **Changing/adding symmetries**
  - SM low-energy effective theory ?
  - SM based on SU(3) x SU(2) x U(1) → Belong to a **larger symmetry group** **?**
    - E6, SO(10), … (e.g. SSM, GUT theories)
  - Breaking ⇒ new symmetries remain ⇒ **additional gauge bosons predicted**
    - e.g. Z', W'

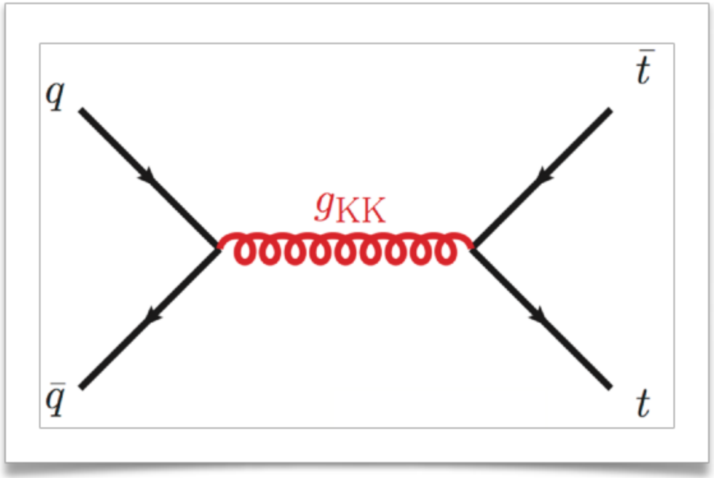




Beyond the Standard Model

Where we go …

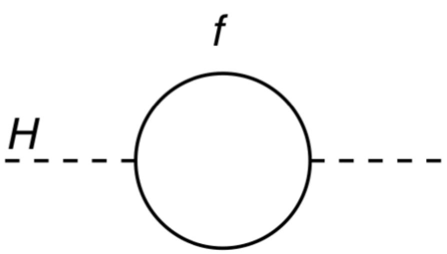
- **New dimensions**
  - Could explain e.g. **mass hierarchy**, scale hierarchy
  - Constraints ⇒ extra-dimensions **compactified**
    - e.g. warped extra-dimensions (Randall-Sundrum)
  - **Excitations of SM particles** ⇒ new particles
    - e.g. Kaluza-Klein gluons, gravitons, …

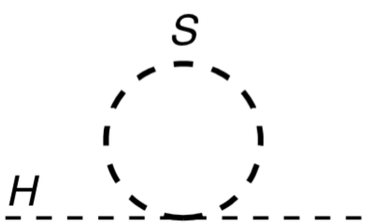


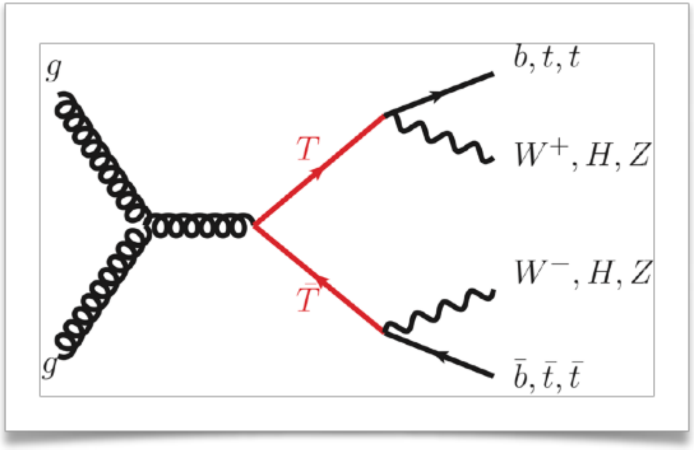
Beyond the Standard Model

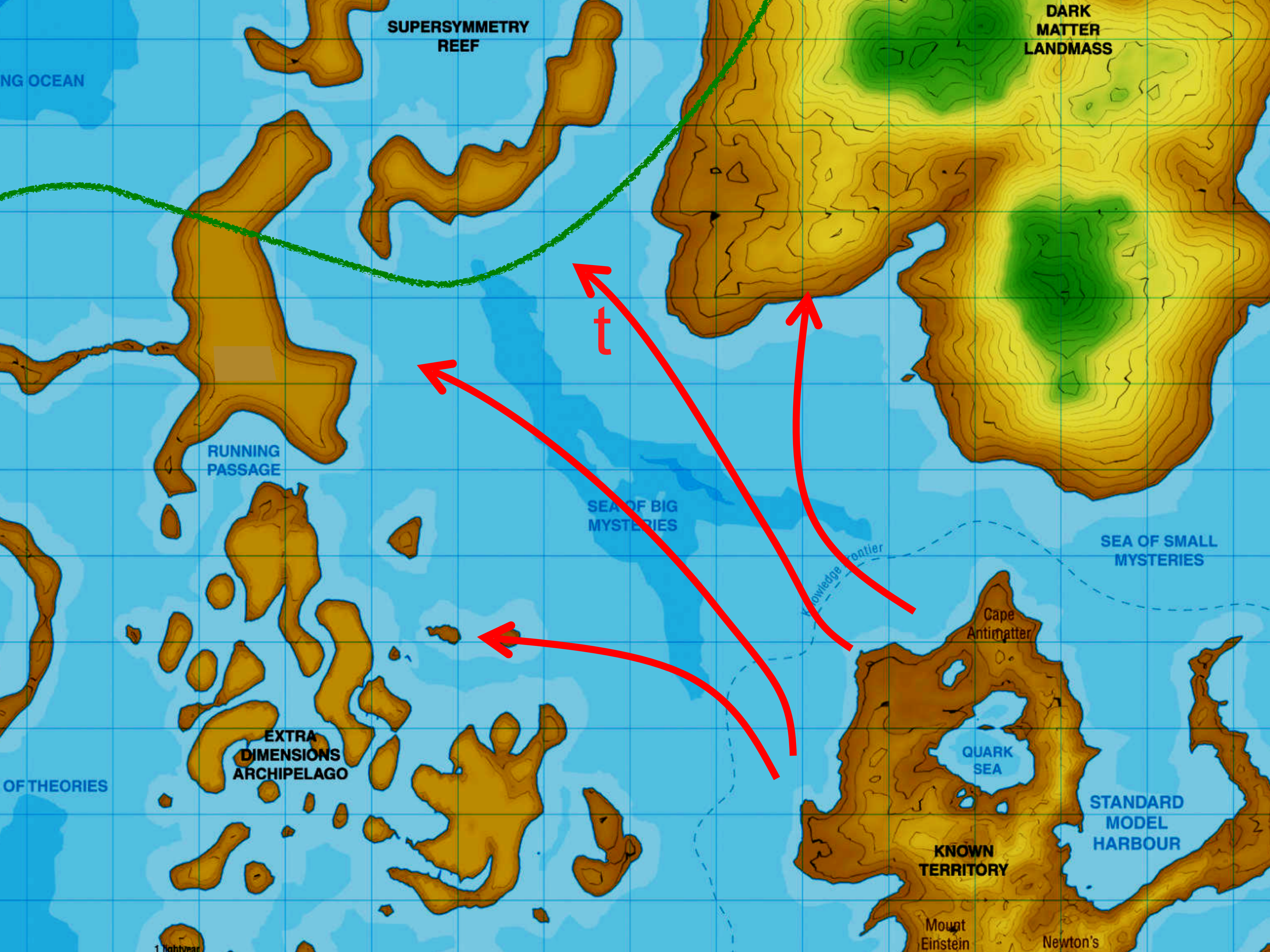
Where we go …

- **Top quark partners**
  - New Physics at higher scale (Planck) ⇒ **could lead to large radiative corrections**
  - Reduction of these corrections: **top quark's partners**
    - superpartners (stops), **vector-like partners** (e.g. Higgs compositeness)





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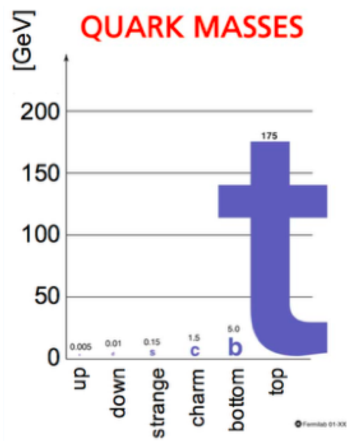
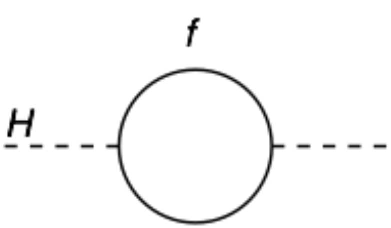
Top quark: probe for New Physics?



Distinctive **properties**
(mass, y_t, …)



Leading radiative corrections
to Higgs mass

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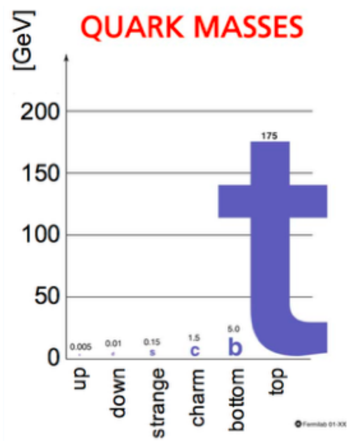

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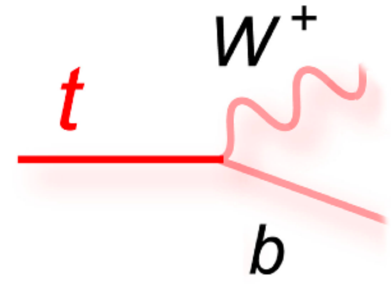
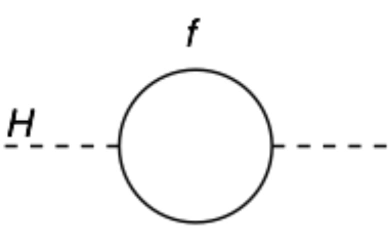


Unique **experimental signature**



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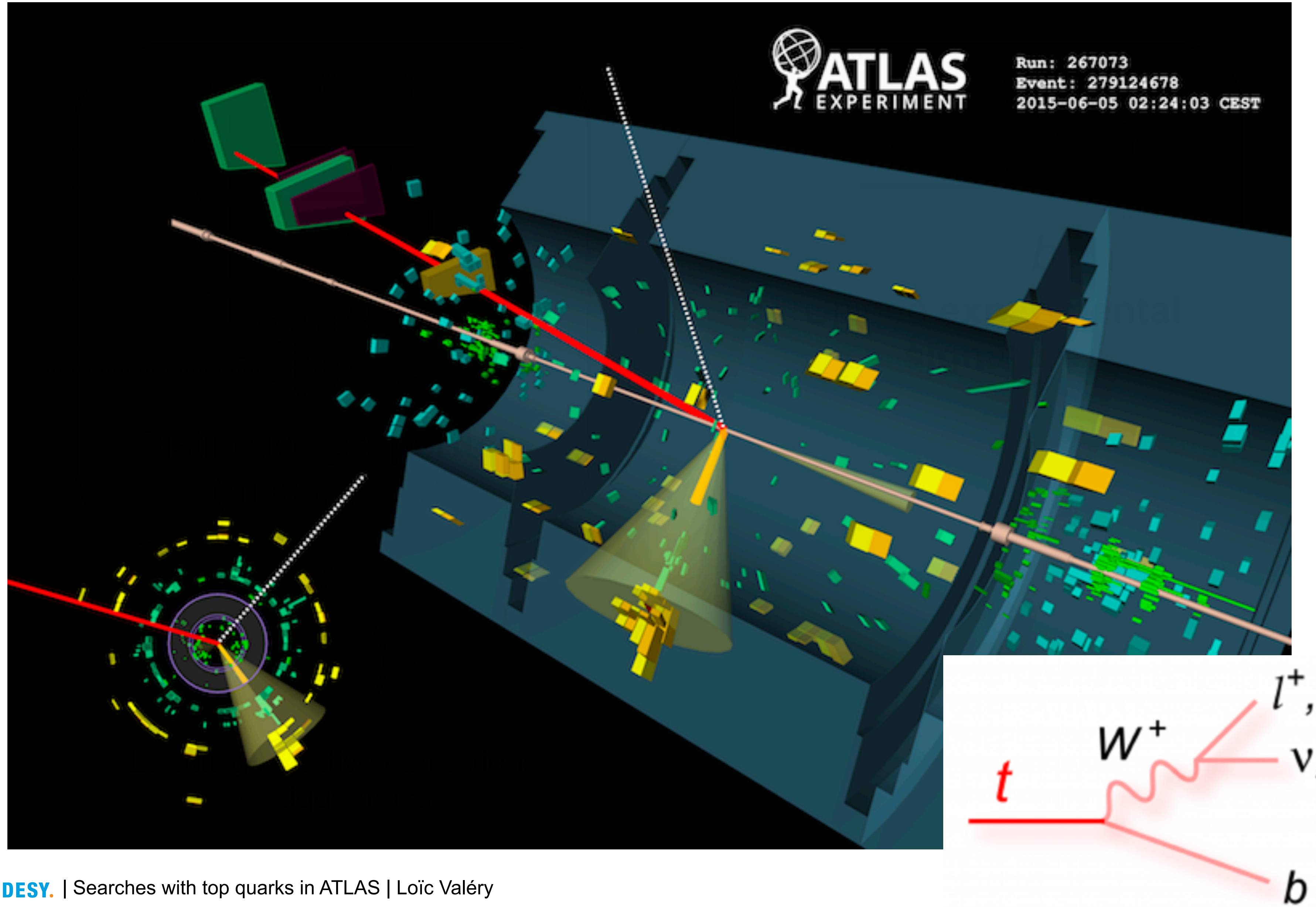
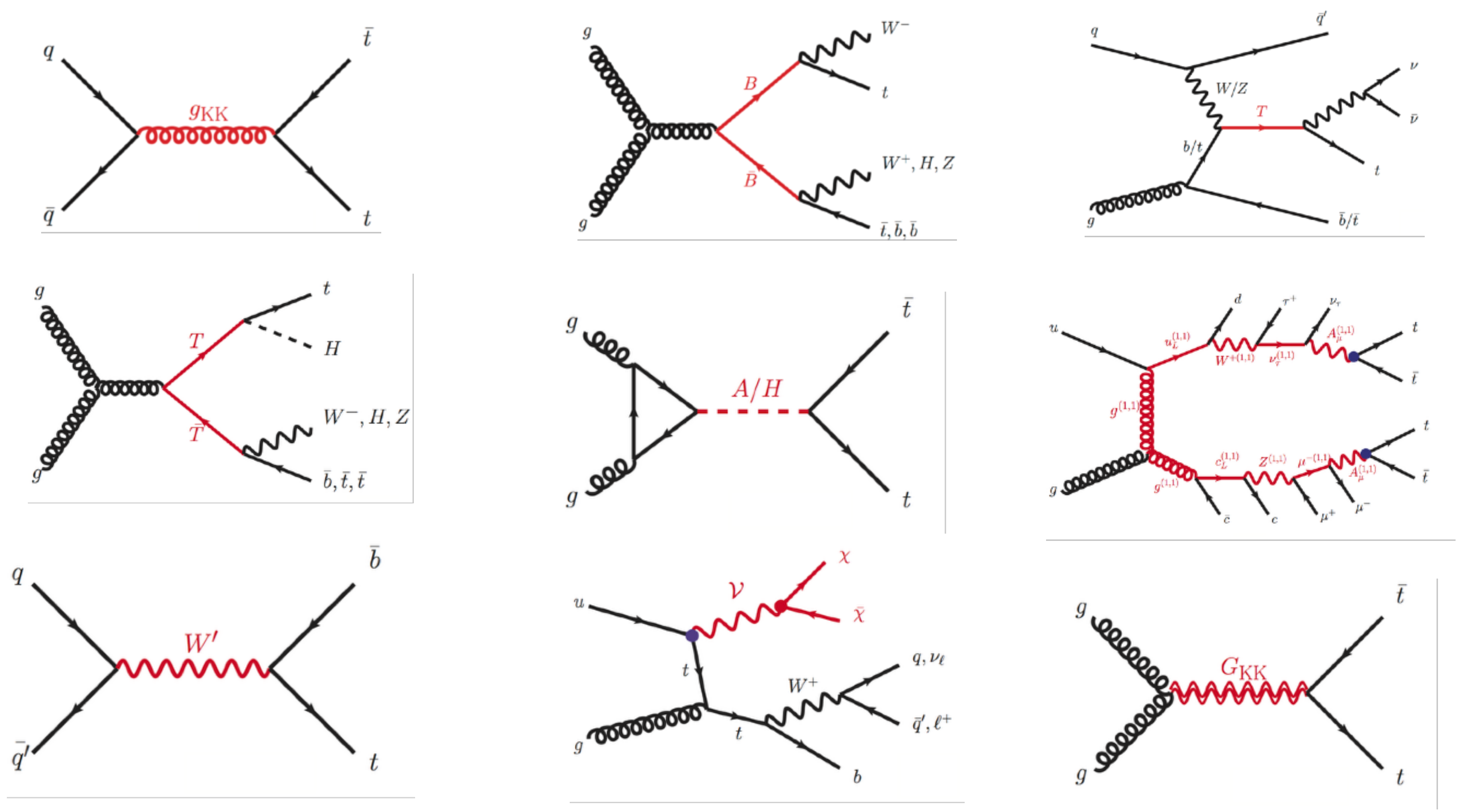


Top quark: probe for New Physics?

- **Large coupling** expected to BSM sector in several models



Top quark: probe for New Physics?

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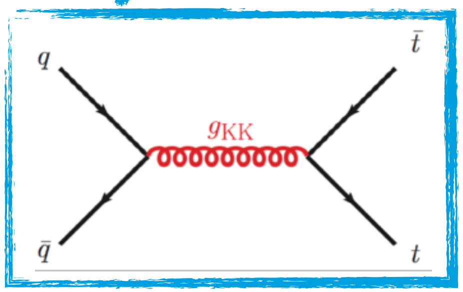
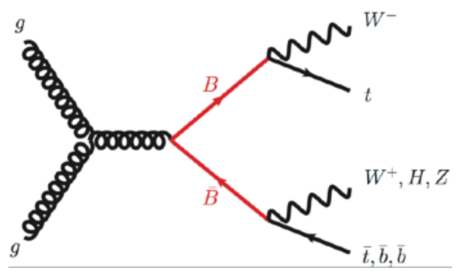
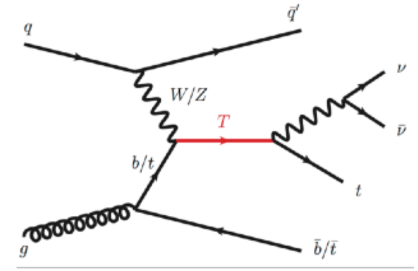
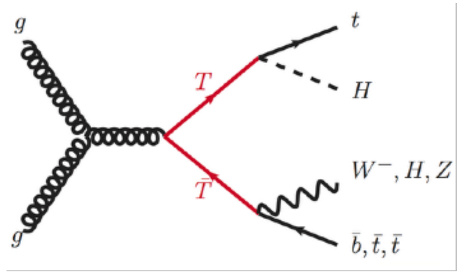
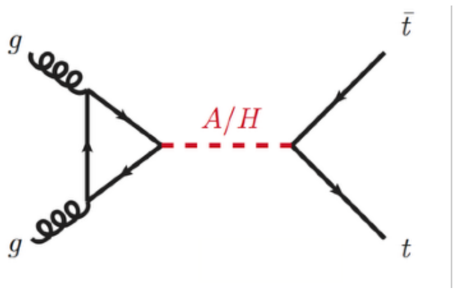
Heavy resonances

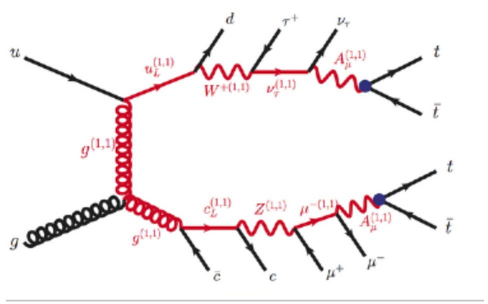


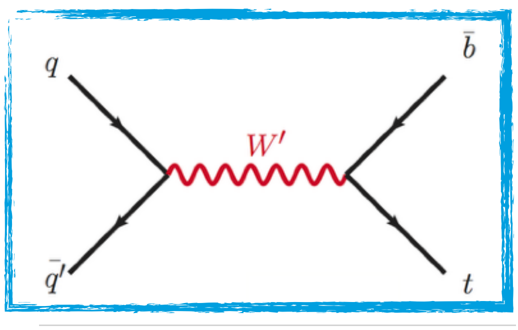


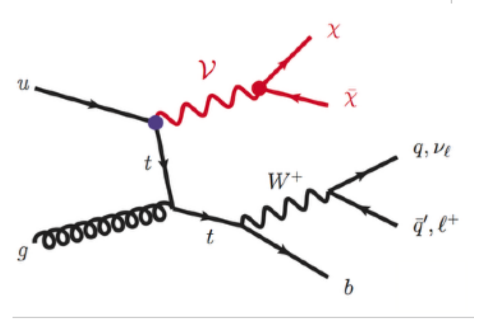


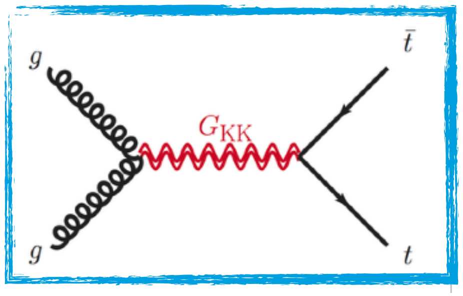










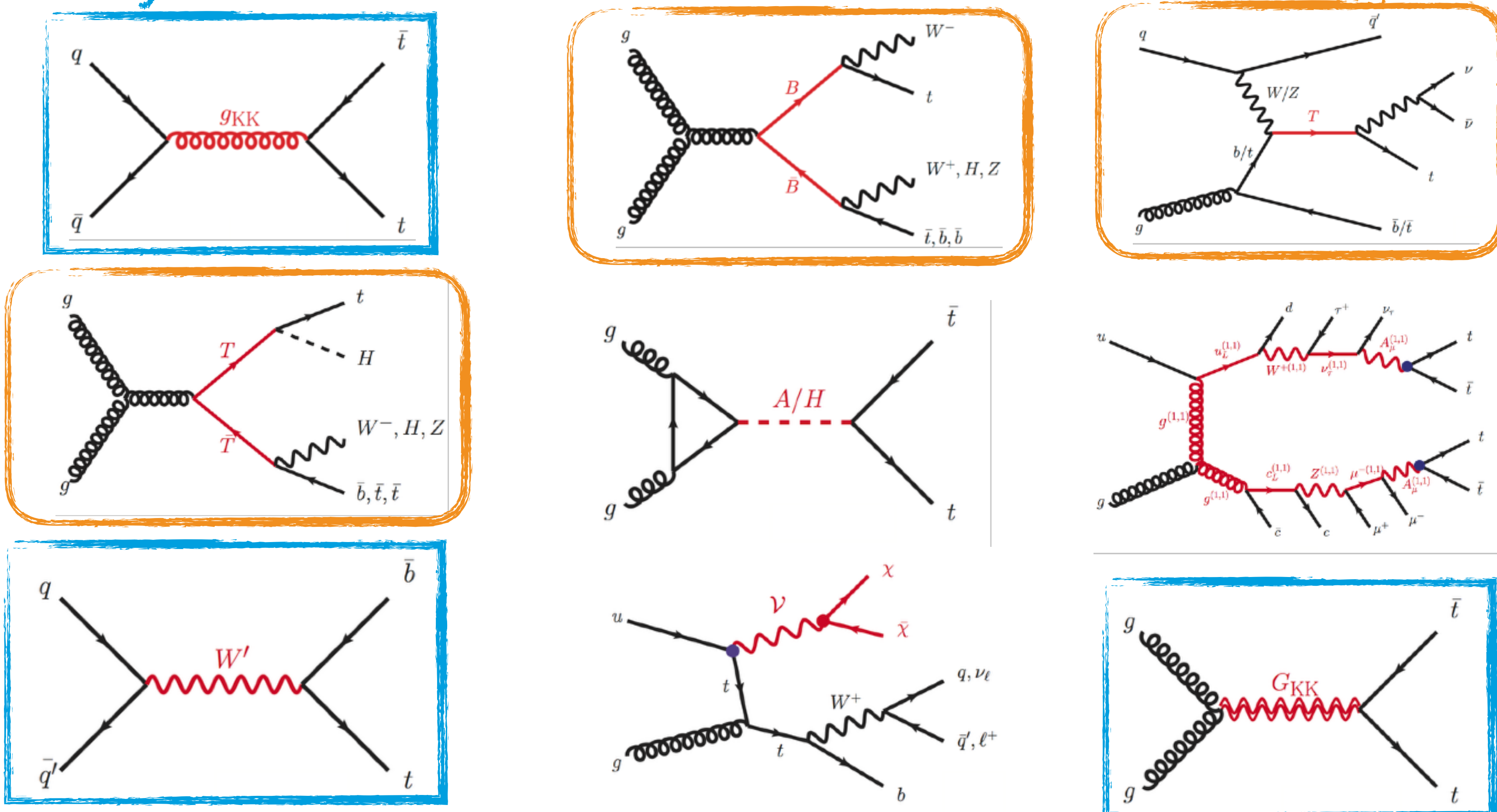


Top quark: probe for New Physics?

- **Large coupling** expected to BSM sector in several models

Heavy resonances

Vector-like quarks

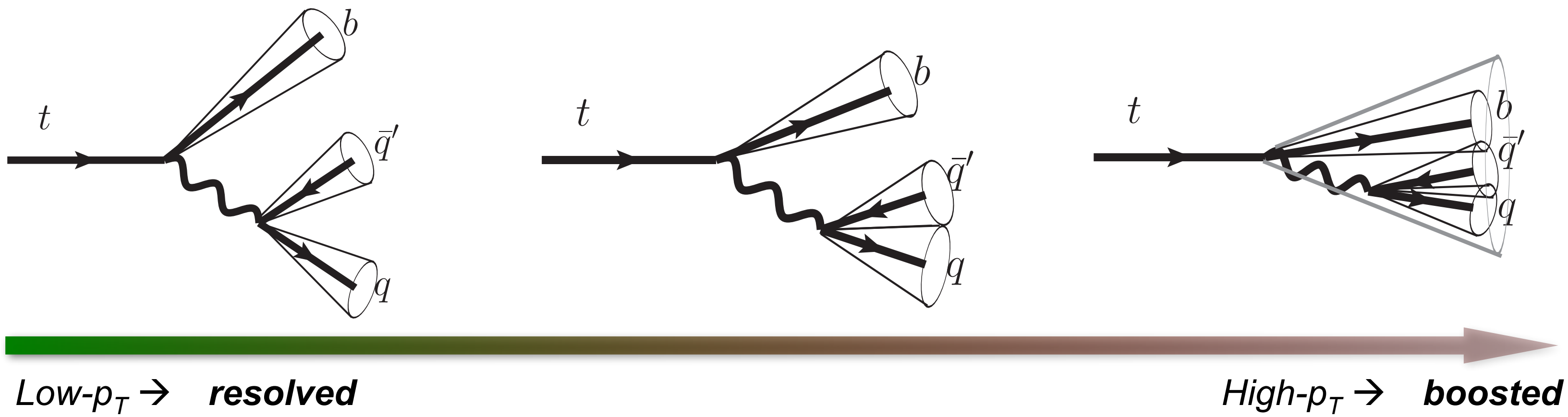


Looking for new physics with top quarks

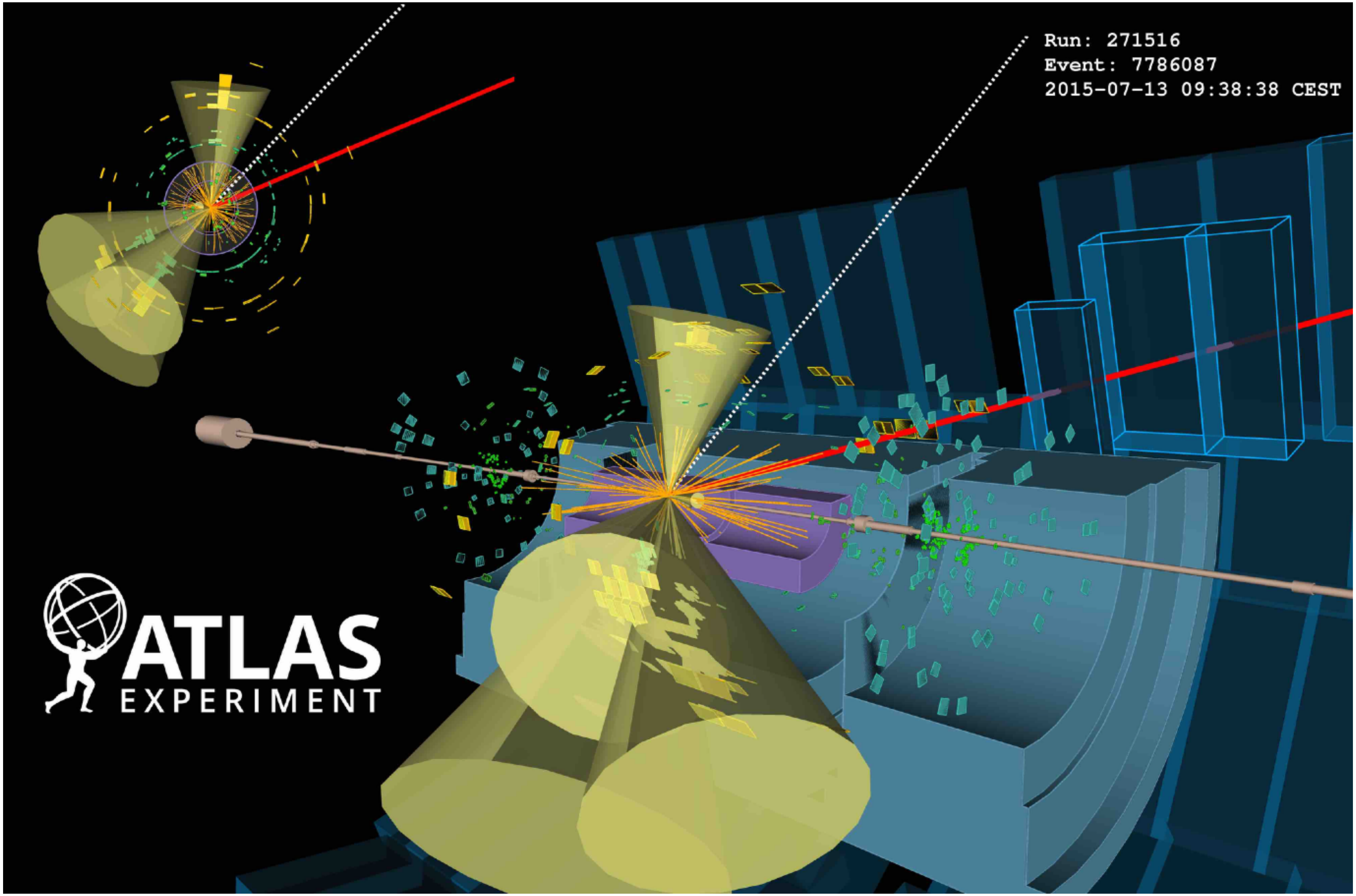
Key features

Event reconstruction

- New **heavy particles**: **high-p_T hadronically-decaying objects**



Event reconstruction



Event reconstruction

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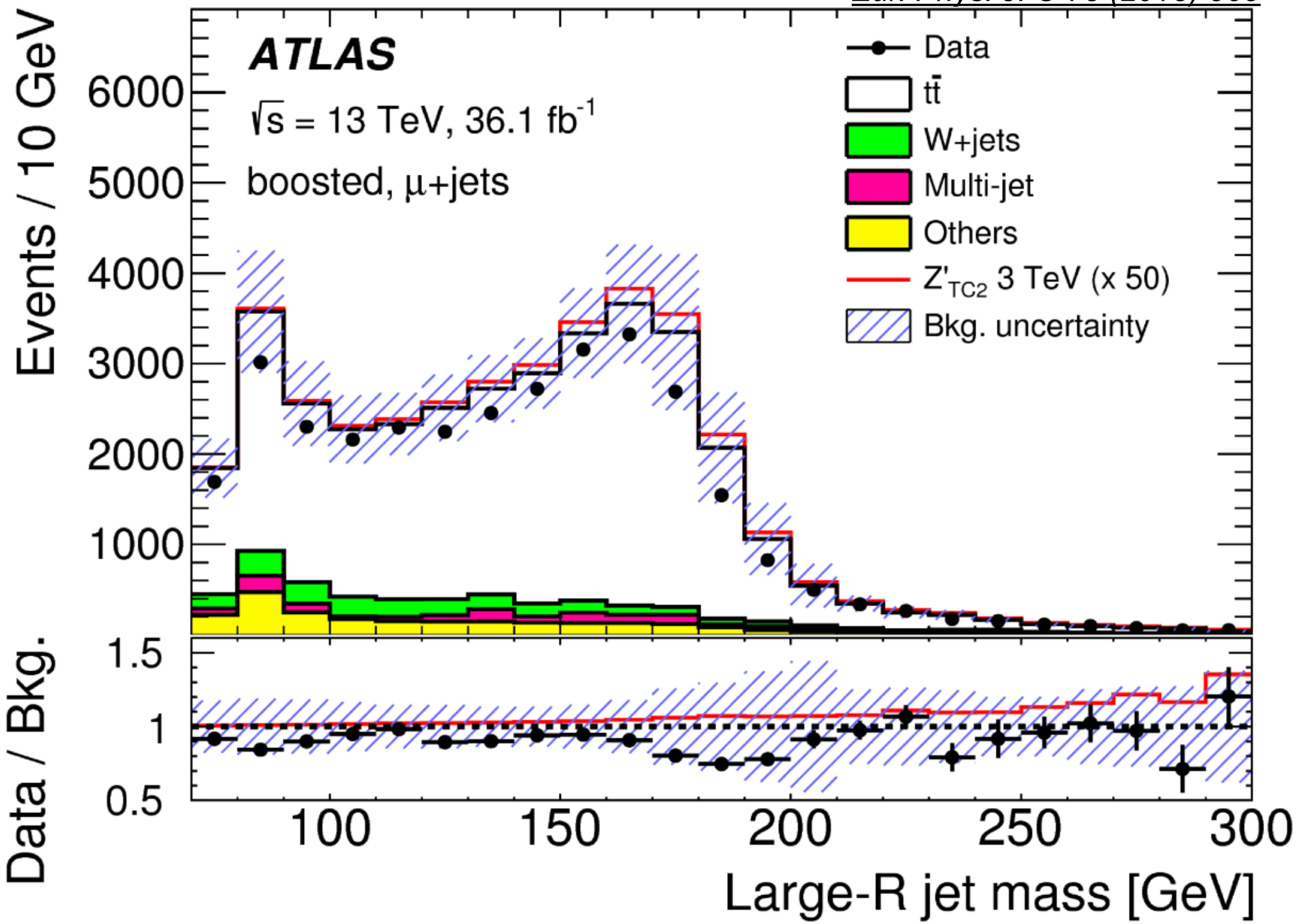
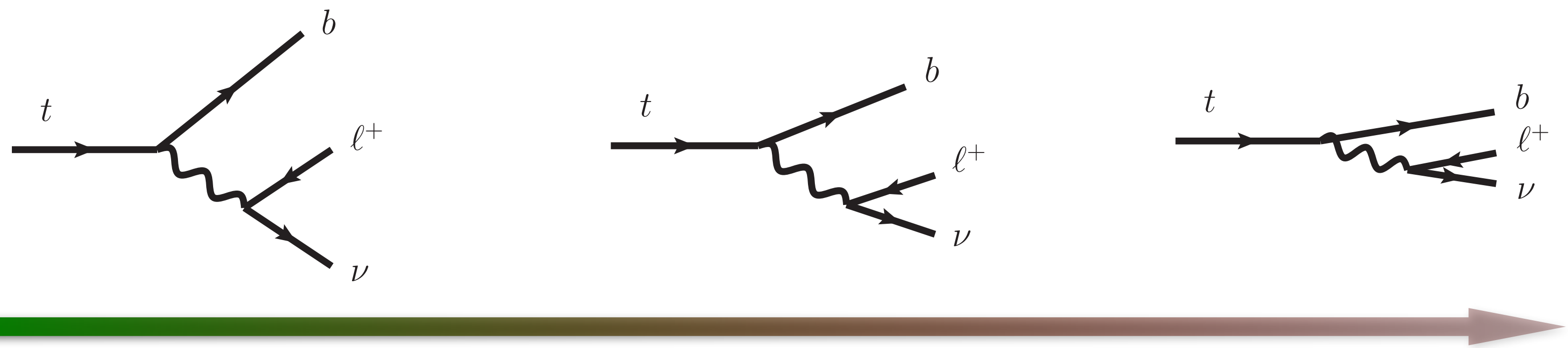


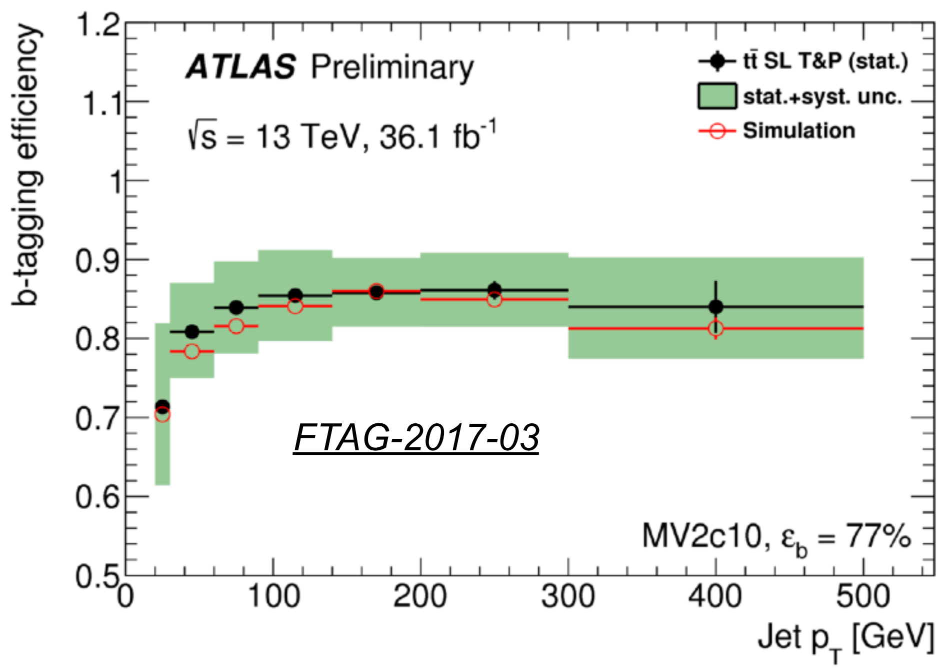
Event reconstruction

- New **heavy particles**: **high-p_T semi-leptonically-decaying objects**

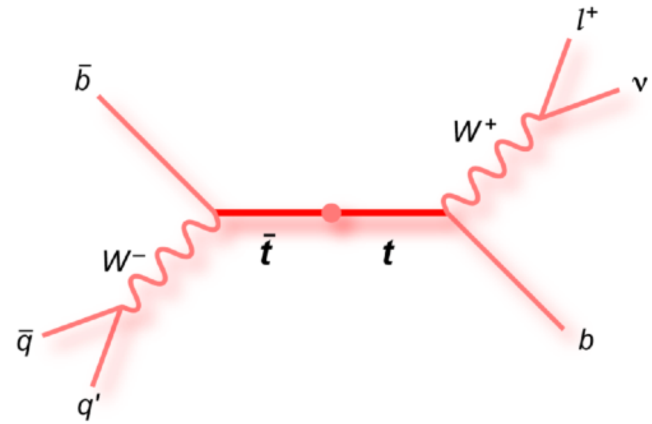


Low-p_T → ***resolved*** *High-p_T* → ***boosted***

- **Key aspects**
  - Lepton **isolation**
  - Impact of **overlapping b-jet**
  - **b-jets** tagging at **high-p_T**



$t\bar{t}$+jets background



- **$t\bar{t}$ + jets** process: often largest background source in top-enriched BSM searches

- Different types probed in searches:
  - many additional jets, b-jets
  - high-p_T top quarks
  - high-p_T top-antitop system

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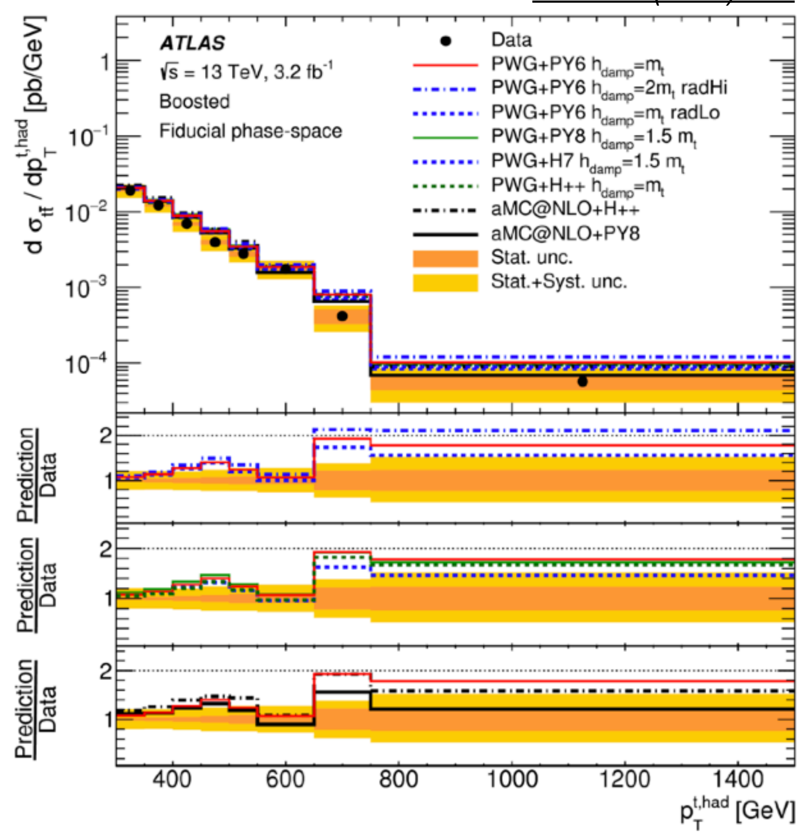

Background estimation strategy adapted to each phase space and observable

Resonance searches

Resonances

- **New heavy leptophobic gauge bosons** (Z', W', g_{KK}, …)
  - Several models probed (e.g. extra-dimension, SSM, Dark Matter)
  - Charge conservation: decays to $t\bar{t}$ or $t\bar{b}$

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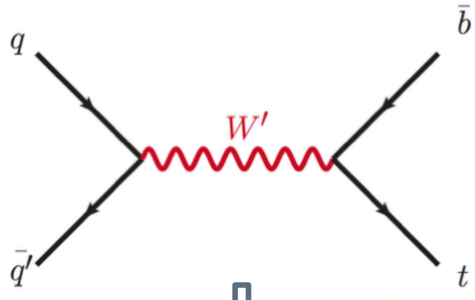
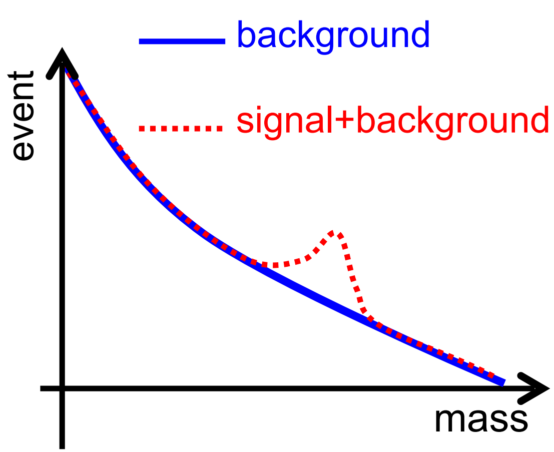


- **Strategy**
  - Continuously falling background
  - New Physics → **bump on invariant mass spectrum**



- **Key aspects**
  - Identification of boosted objects (e.g. boosted top quarks)
  - **Reconstruction** of invariant mass
  - **Background shape** modelling

$t\bar{t}$ resonances

1-lepton channel

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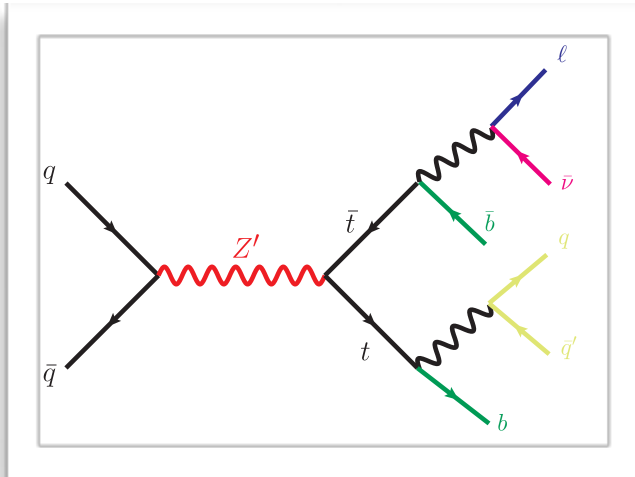

Lepton + MET + ≥1 b-jet → No → *Event rejected*

↓ Yes

Boosted
≥1 "hadronic top" large-R jet
Close lepton and b-jet

↓ Yes

Selected as "Boosted"

$t\bar{t}$ resonances

1-lepton channel

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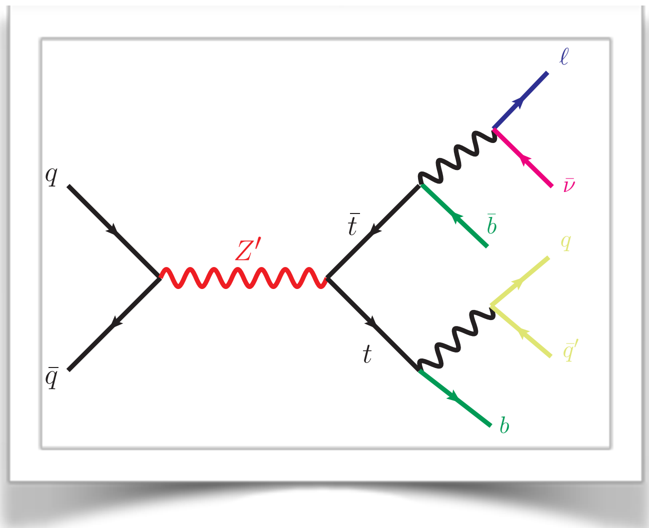

Lepton + MET + ≥1 b-jet

No → *Event rejected*

Yes ↓

Boosted
≥1 "hadronic top" large-R jet
Close lepton and b-jet

Yes ↓ *Selected as "Boosted"*

No → *Resolved*
≥4 jets
Reconstruction algorithm

No ↑ *Event rejected*

Yes ↓ *Selected as "Resolved"*

$t\bar{t}$ resonances

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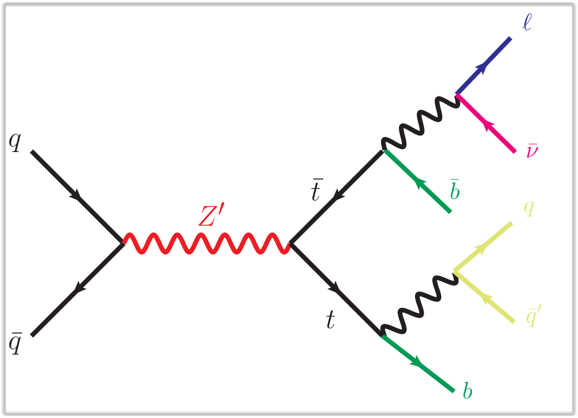
1-lepton channel



Lepton + MET + ≥1 b-jet → No → *Event rejected*

Yes ↓

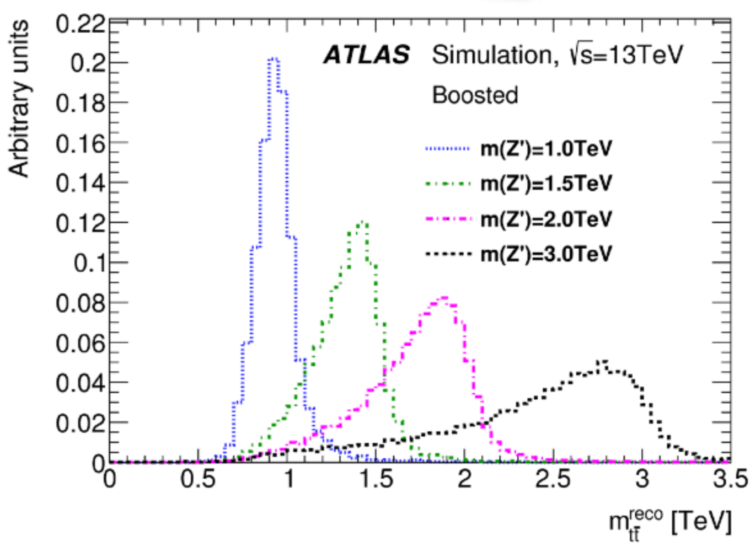
Boosted
≥1 "hadronic top" large-R jet
Close lepton and b-jet

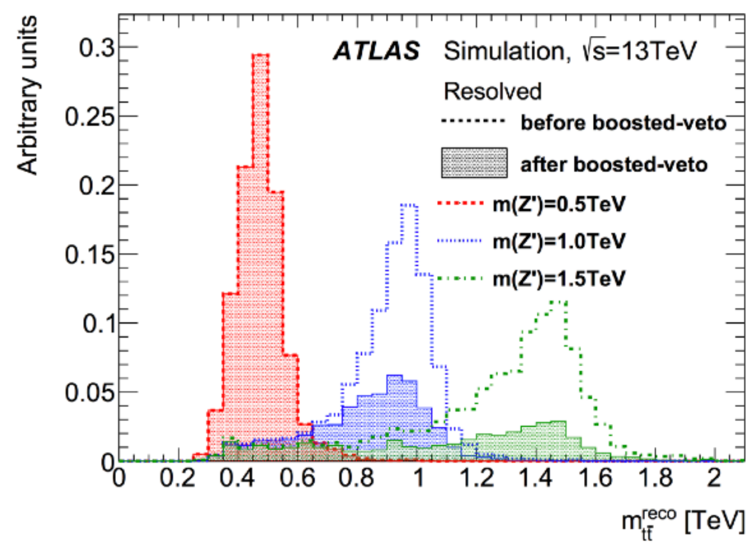
No → *Resolved*
≥4 jets
Reconstruction algorithm

Resolved: No ↑ *Event rejected*

Boosted: Yes ↓ *Selected as "Boosted"*

Resolved: Yes ↓ *Selected as "Resolved"*





$t\bar{t}$ resonances

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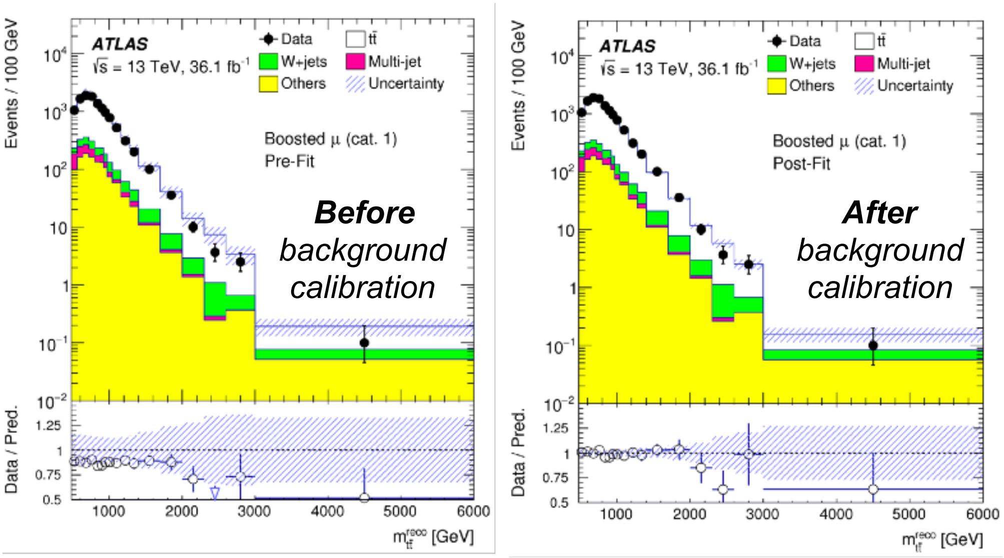
1-lepton channel

- $m_{t\bar{t}}$ spectrum compared between data and background prediction
  - Data/prediction agreement can be improved → **background calibration**
    - simultaneous profile likelihood fit in all channels with all nuisance parameters



$t\bar{t}$ resonances

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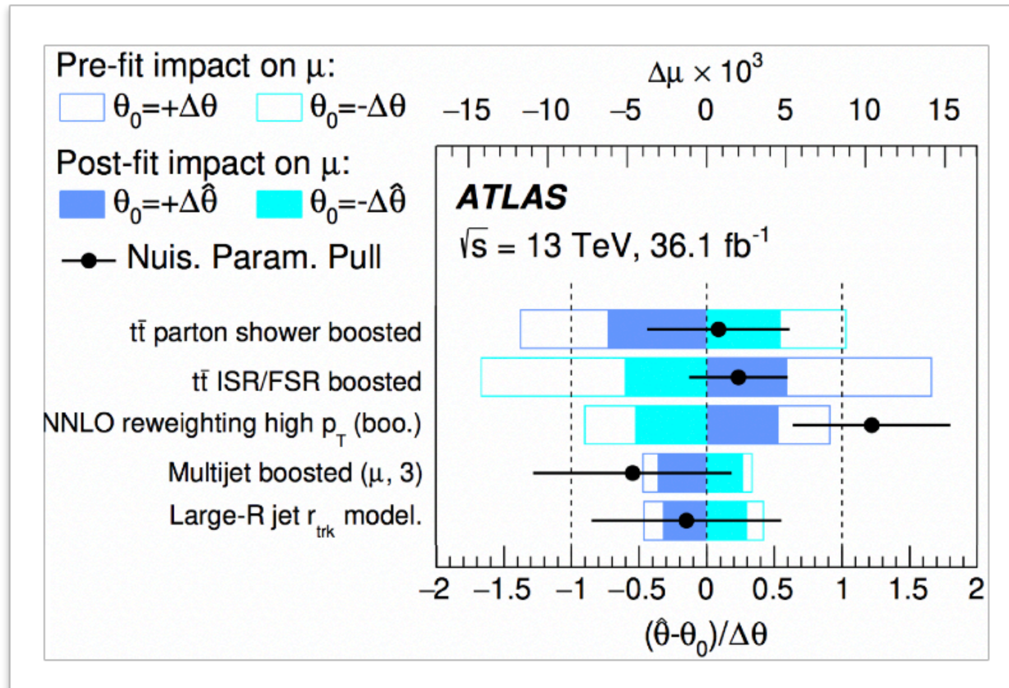
1-lepton channel

- Background estimate **parameters**
  - Background **normalisation**
  - MC generator **settings**
  - **Alternative** generators
- Background calibration
  - **Background model fit to data**



Extracted from Eur. Phys. J. C 78 (2018) 565

$t\bar{t}$ resonances

1-lepton channel

Eur. Phys. J. C 78 (2018) 565

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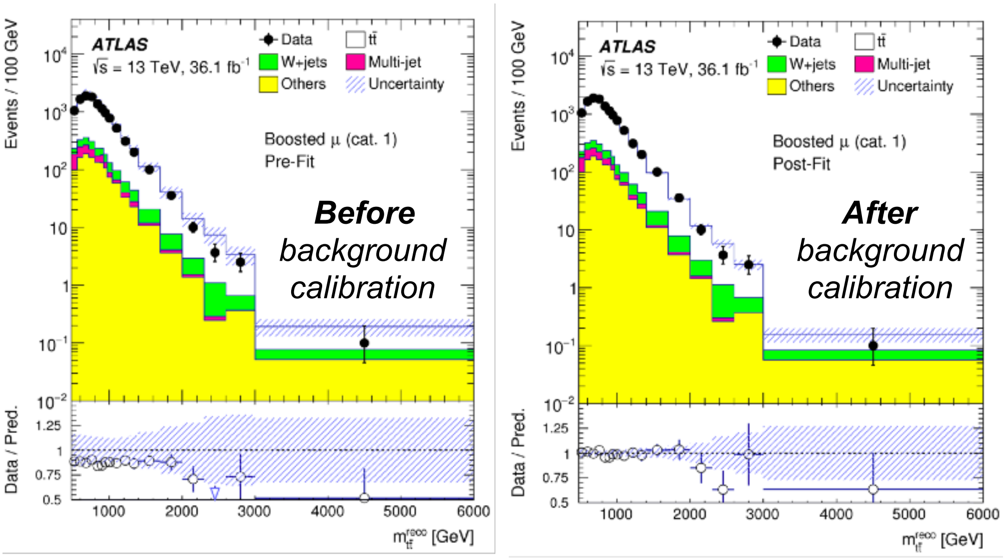

$t\bar{t}$ resonances

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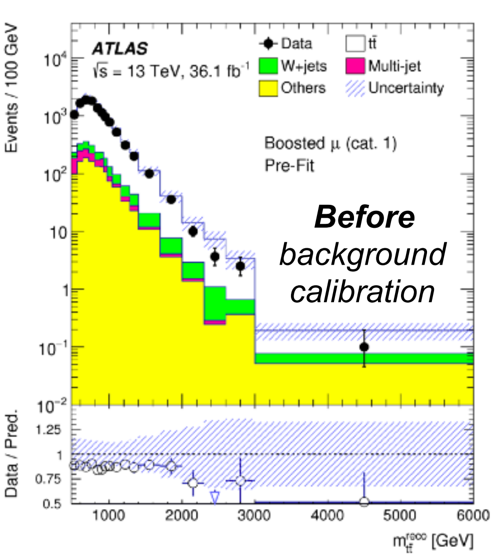
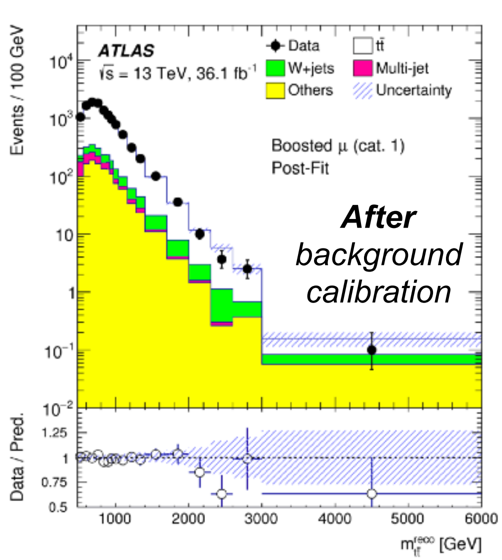
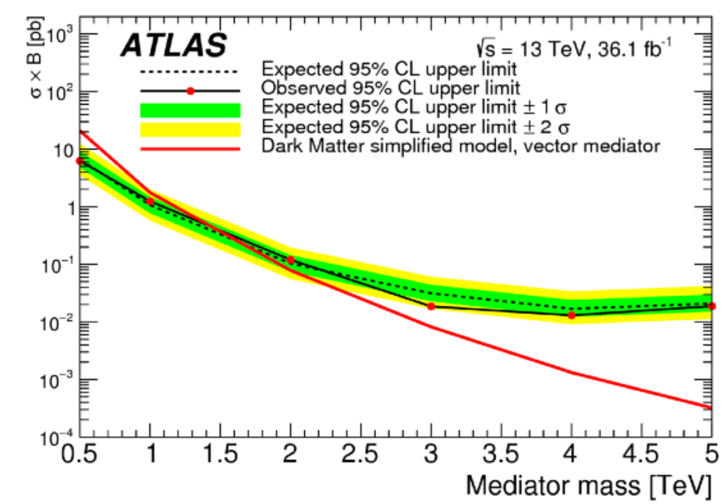
1-lepton channel

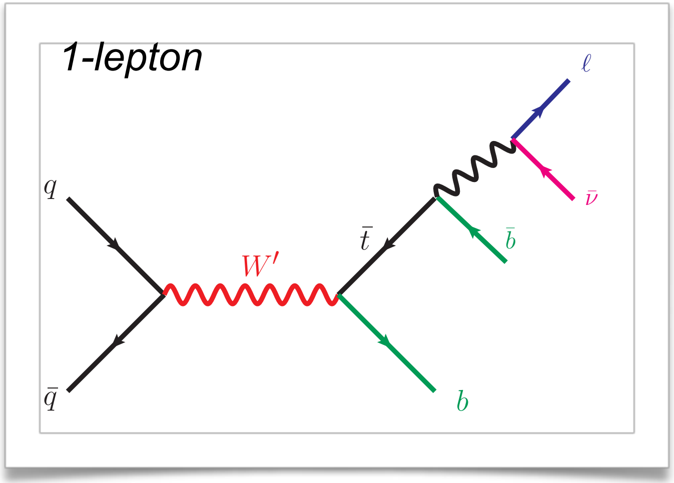
- $m_{t\bar{t}}$ spectrum compared between data and background prediction
  - Data/prediction agreement can be improved → **background calibration**
    - simultaneous profile likelihood fit in all channels with all nuisance parameters
  - After fit, **very good agreement with prediction**
- Bumps searched for in all channels → **no significant bump observed**
- CL_s limits set at 95% CL for various **models**, **masses** and **widths**







$t\bar{b}$ resonances



1 lepton ?

Yes

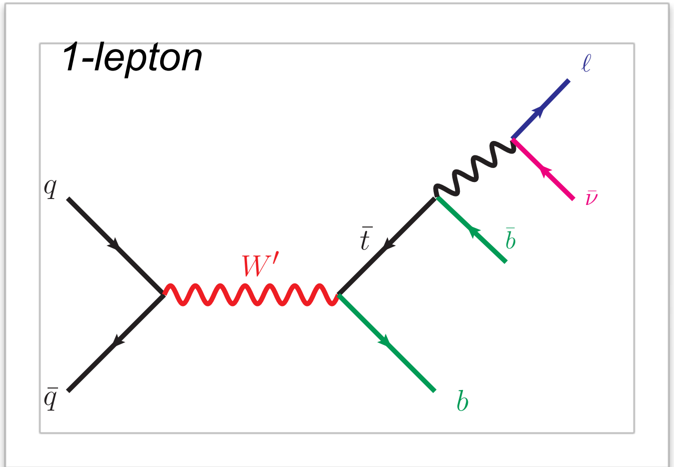
Lepton + jets
2 or 3 jets (1 or 2 b-jets)
Close lepton and b-jet

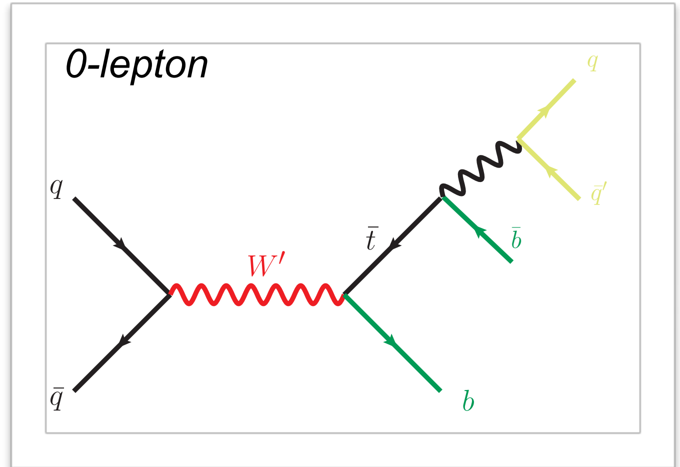
No → *Event rejected*

Yes

Selected as "l+jets"

$t\bar{b}$ resonances





1 lepton ?

No →

All-hadronic
1 “hadronic top”
Small-R jet away from “top”

Yes → *Selected as “all-hadronic”*

No ↓ *Event rejected*

Yes ↓

Lepton + jets
2 or 3 jets (1 or 2 b-jets)
Close lepton and b-jet

No → *Event rejected*

Yes ↓

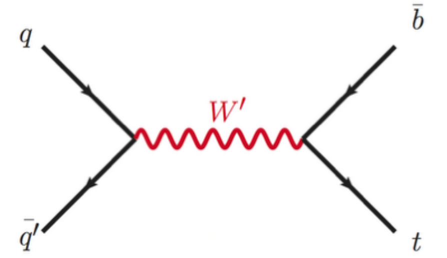
Selected as “l+jets”

t$\bar{b}$ resonances

1-lepton search

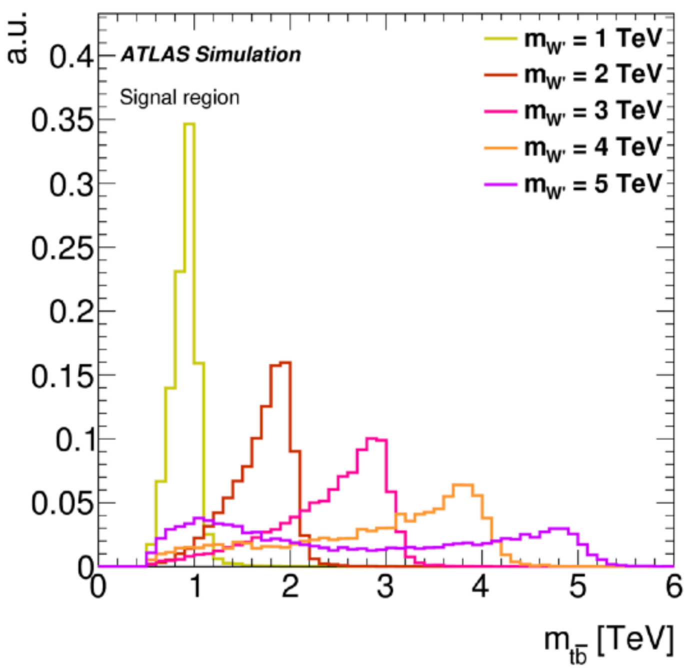
arXiv:1807.10473

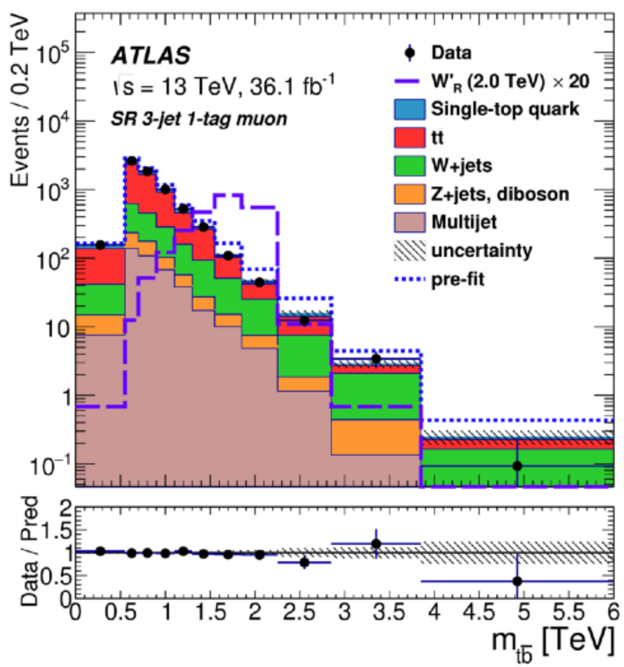
Accepted by PRD



- Event **reconstruction**
  - W' candidate: combination of lepton, MET and b-jet candidate
  - Resolution effects: combinatorics and PDF

- After fit, background prediction in good agreement with data

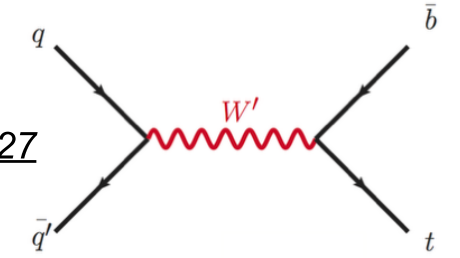




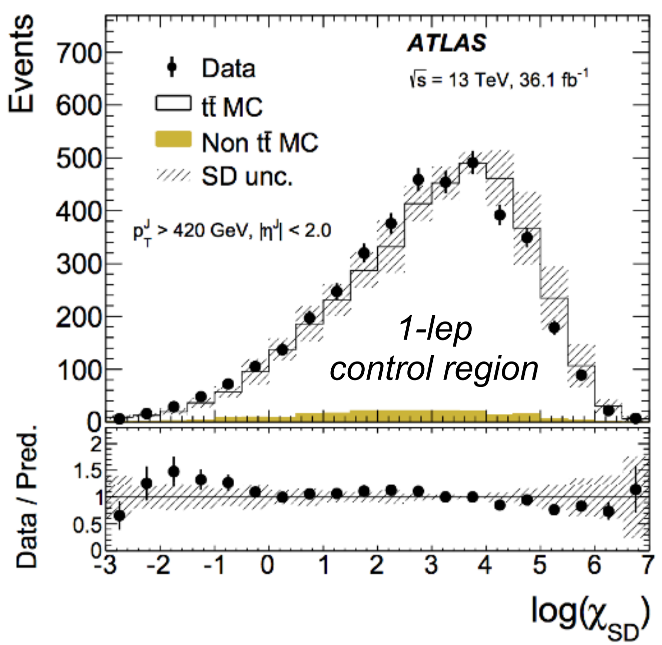
$t\bar{b}$ resonances

0-lepton search

Phys. Lett. B 781 (2018) 327



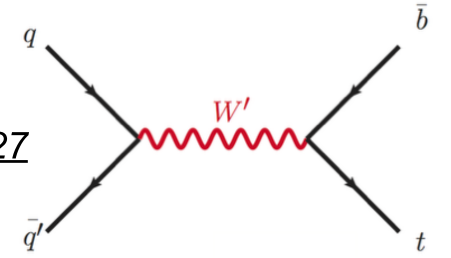
- **Top-tagging** algorithm
  - Using **shower deconstruction** (SD) algorithm on large-R jets *[Phys. Rev. D 84, 074002]*
    - consider all possible shower histories leading to subjet configuration
    - **variable of interest** (likelihood ratio): χ_{SD}



$t\bar{b}$ resonances

0-lepton search

Phys. Lett. B 781 (2018) 327



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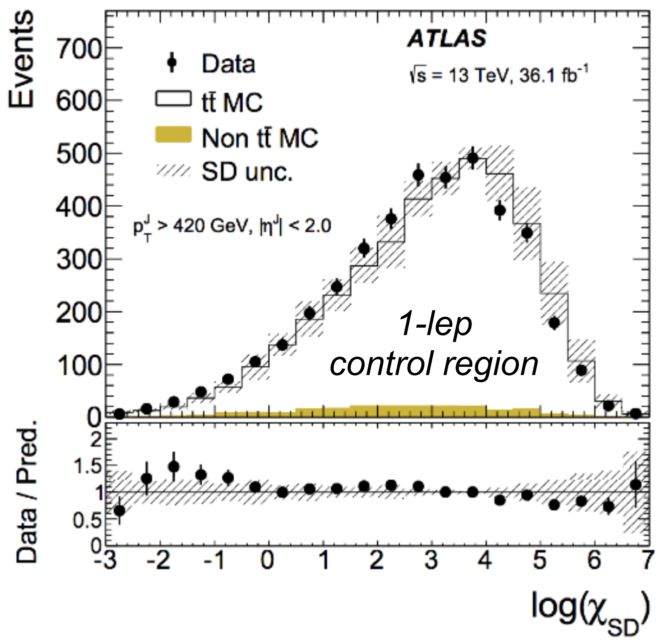
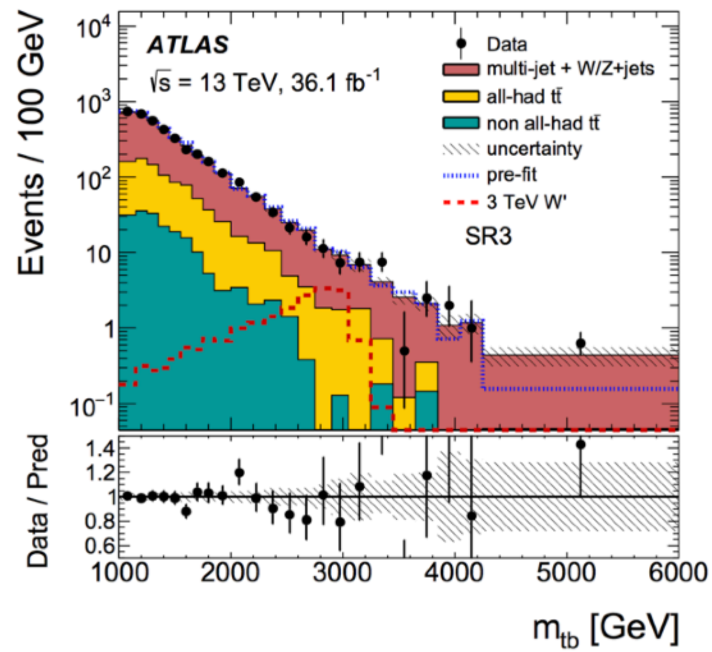
  - Using **shower deconstruction** (SD) algorithm on large-R jets *[Phys. Rev. D 84, 074002]*
    - consider all possible shower histories leading to subjet configuration
    - **variable of interest** (likelihood ratio): χ_{SD}
- Data-driven **multijet background** estimation
- **Very good data/prediction agreement** across all bins and regions

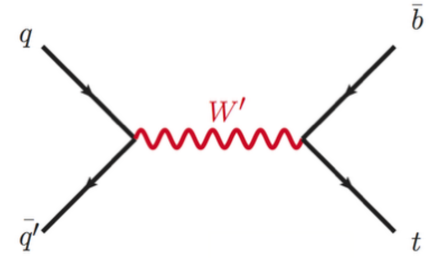




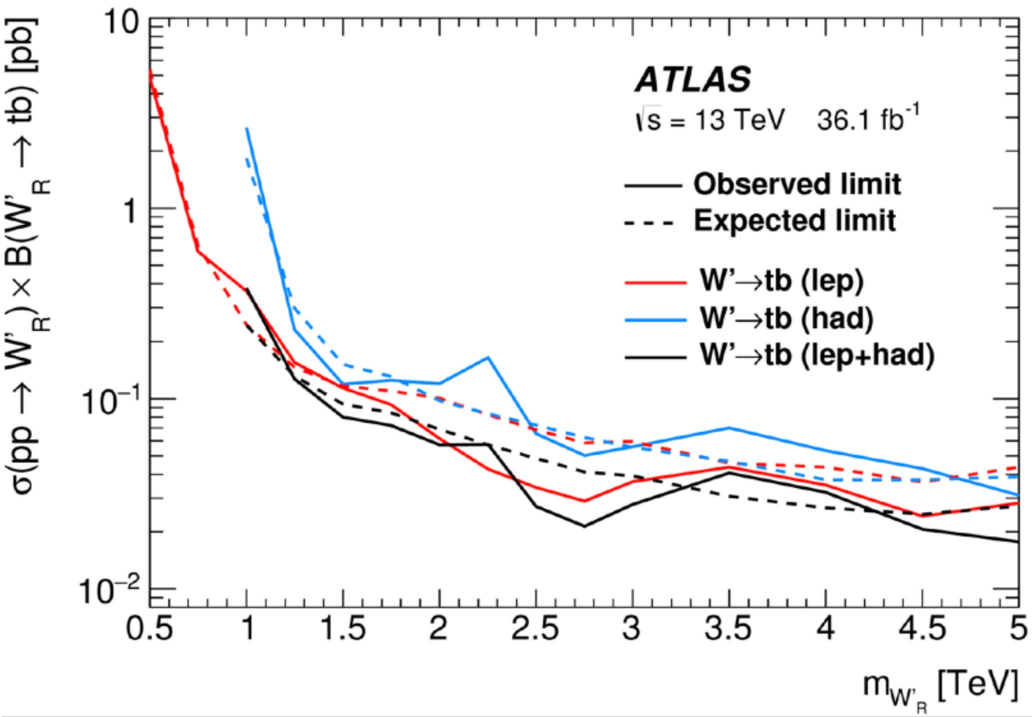
$t\bar{b}$ resonances

Combination

arXiv:1807.10473
Accepted by PRD

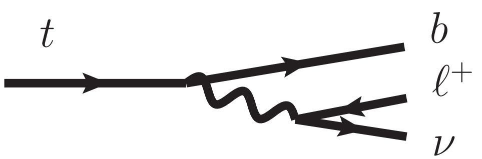


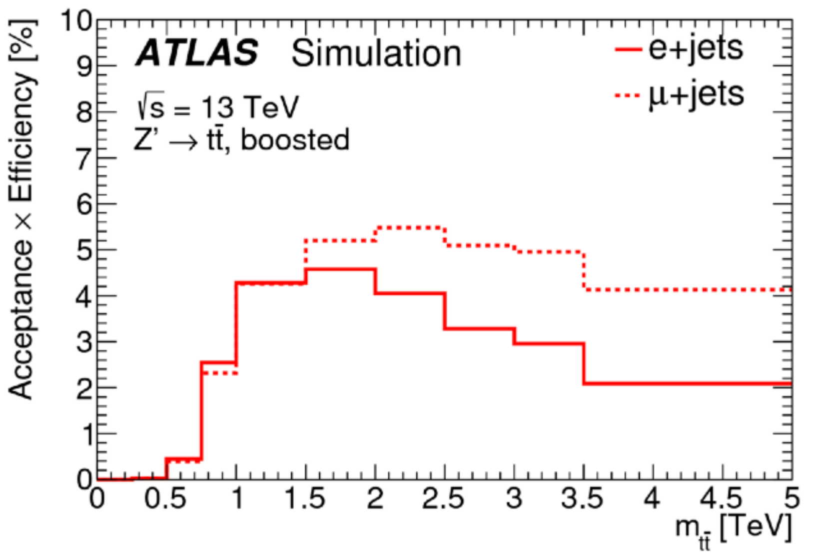
- 1- and 0-lepton searches: **similar sensitivity**
- **Different** dominating **background sources**
- Combination: **expected sensitivity improved by factor ~2**



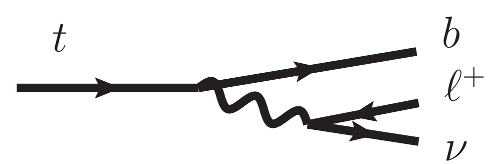
Resonances: a few lessons learnt ?

- High mass regime: statistics is limiting
- **Event selection**
  - *Electrons close to jets*: electron channel less powerful
  - *High-p_T jets b-tagging:* efficiency loss at high p_T (more likely to miss high-p_T b-jets)





Resonances: a few lessons learnt ?



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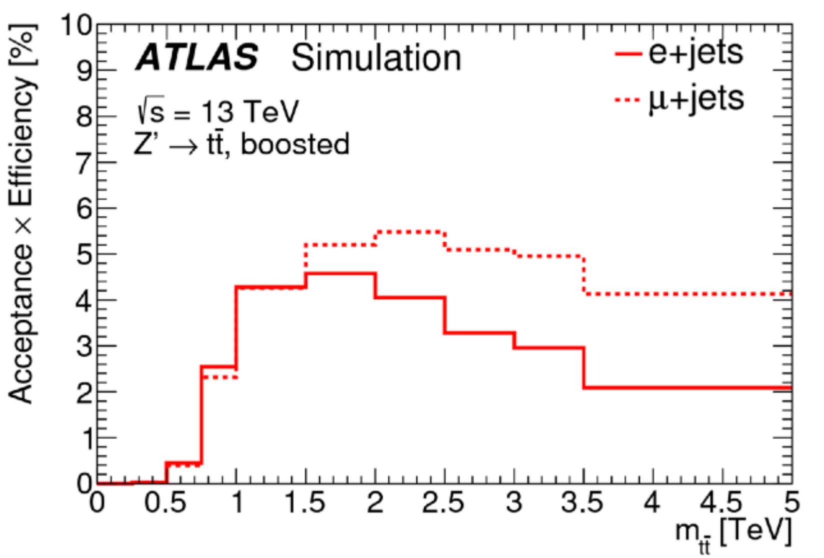

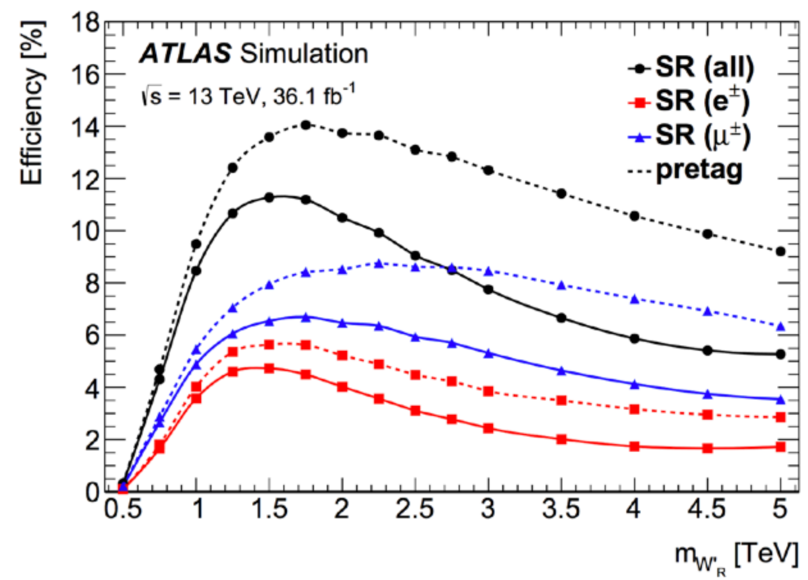

- **Improvements** ongoing for next generation (e.g. ATL-PHYS-PUB-2017-013)

Vector-like quark searches

Vector-like quarks

- **Heavy quarks** for which **left-** and **right-handed** chirality components transform the same under SU(2)
  - Predicted in **many theories** (extra-dimensions, Higgs compositeness, …)
  - Gauge invariant mass term

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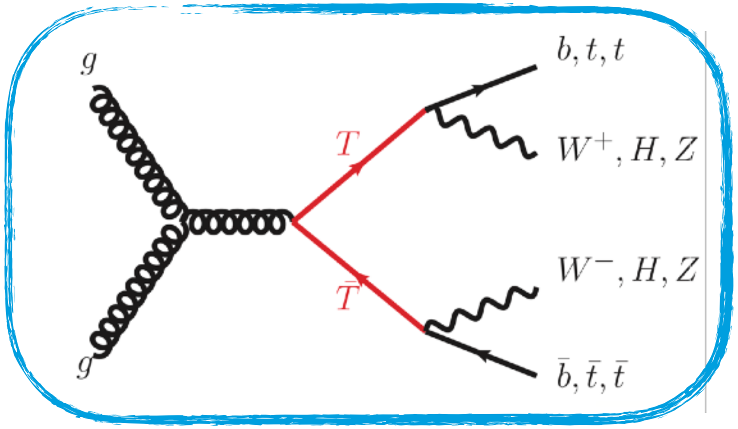
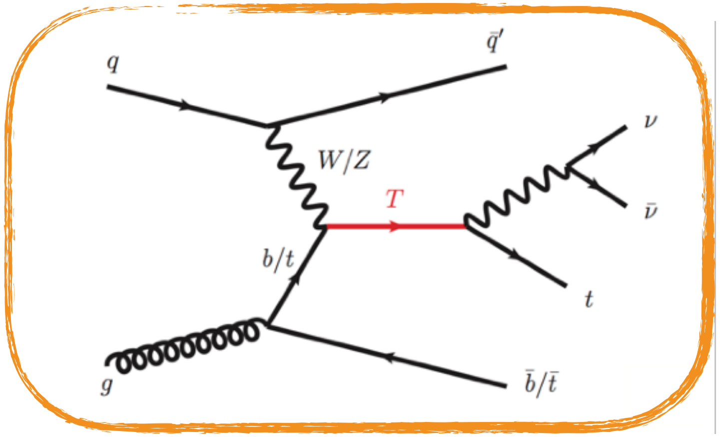
Pair-production



- Production ~independent on VLQ coupling to SM partners
- Dominant for **low masses**

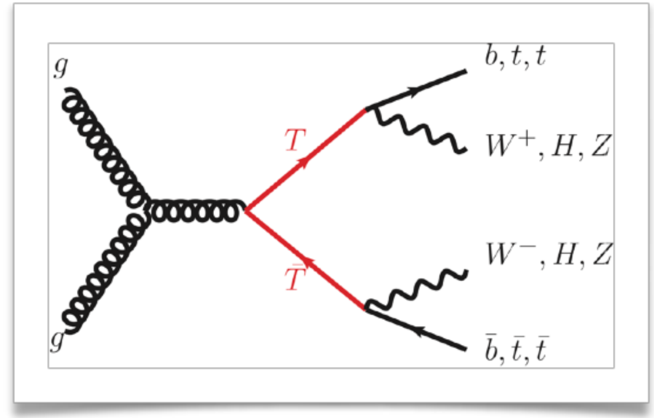
Single-production

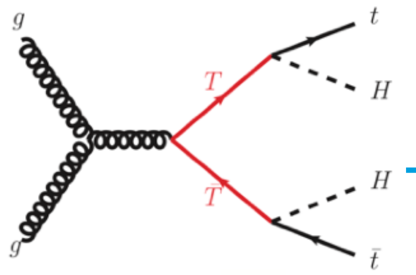


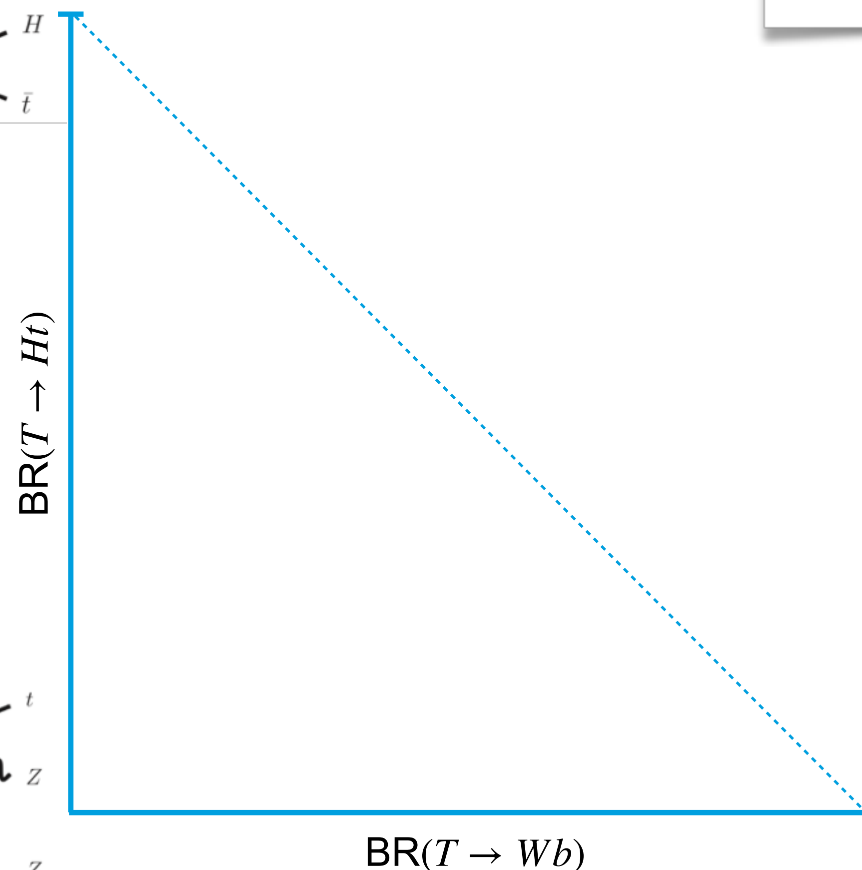
- Cross-section depends on VLQ coupling assumptions
- Can be dominant for **high masses**

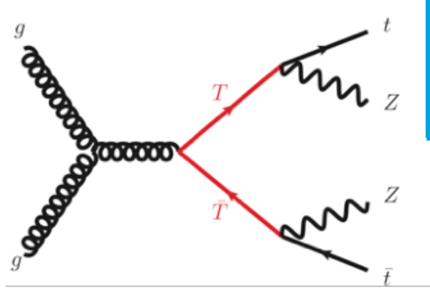
Pair-production searches

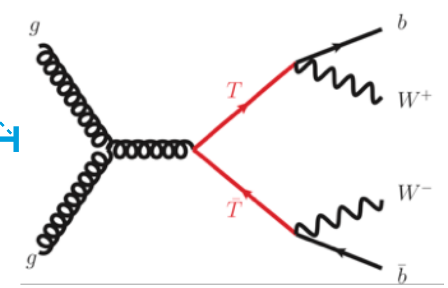
Decay configurations





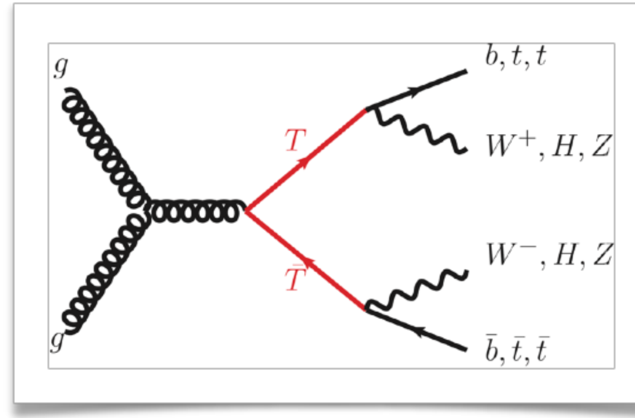


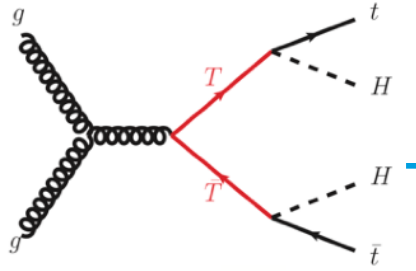


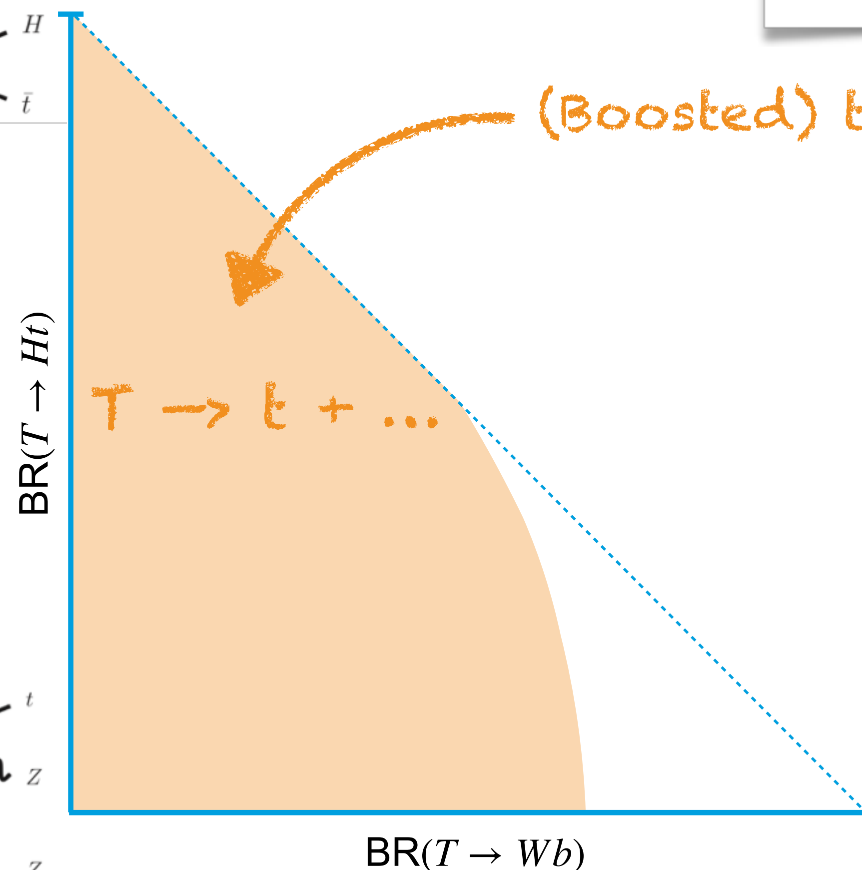


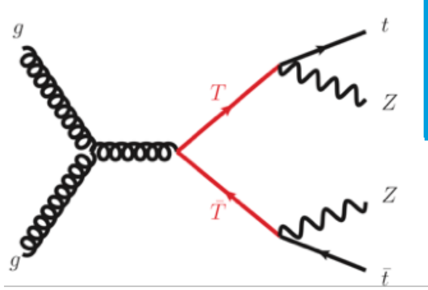
Pair-production searches

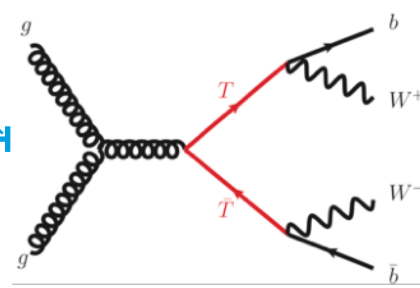
Decay configurations





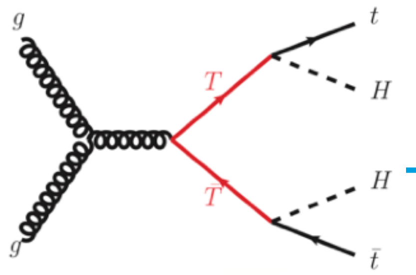


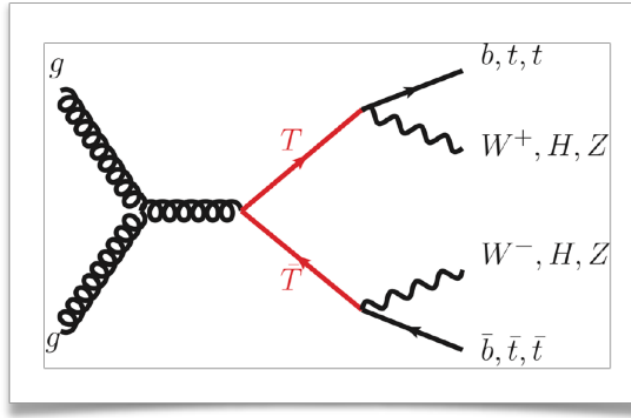


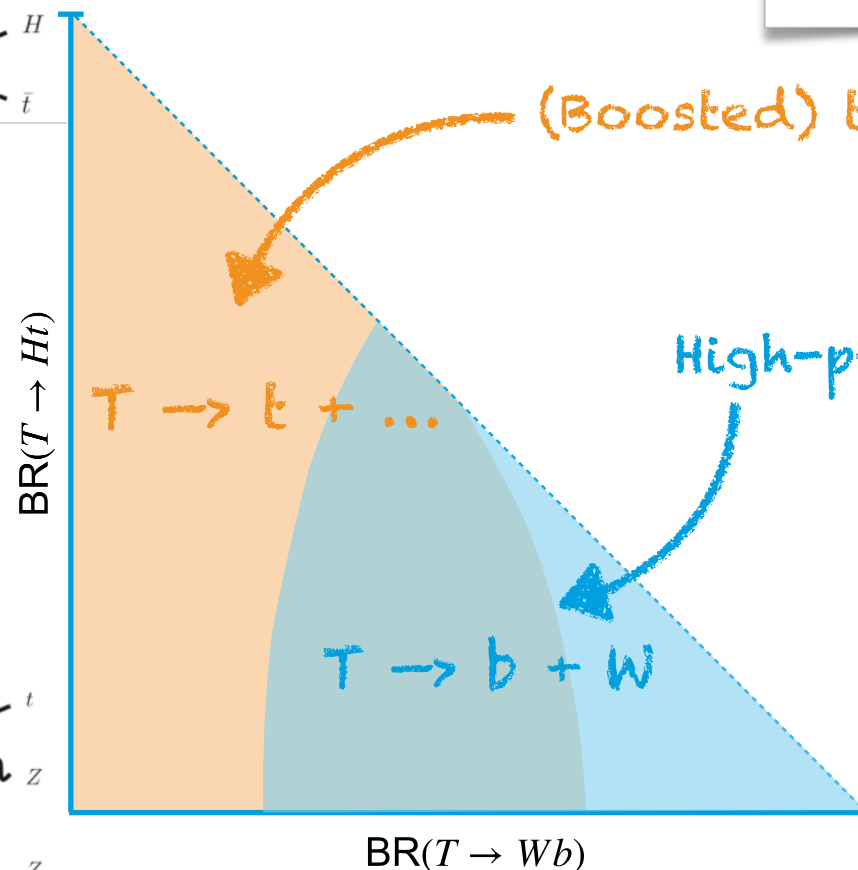


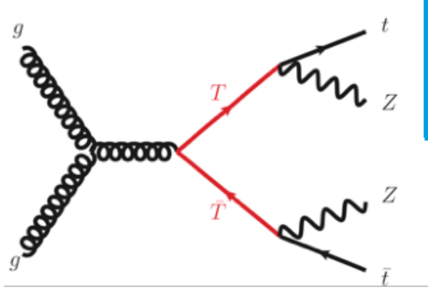
Pair-production searches

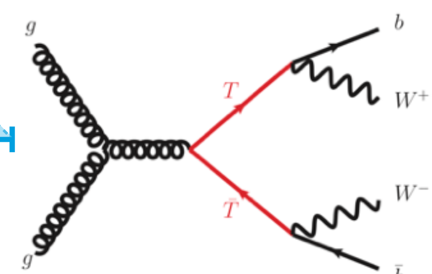
Decay configurations











Pair-production searches

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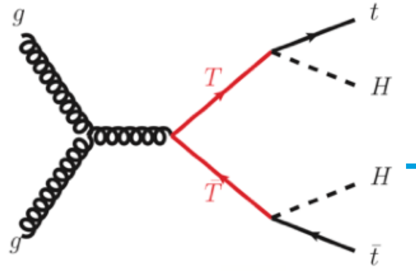

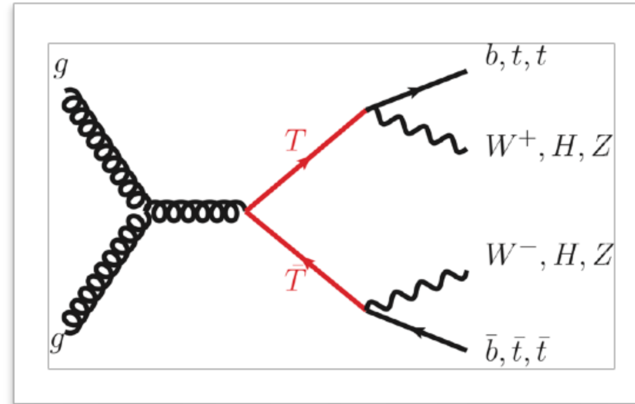

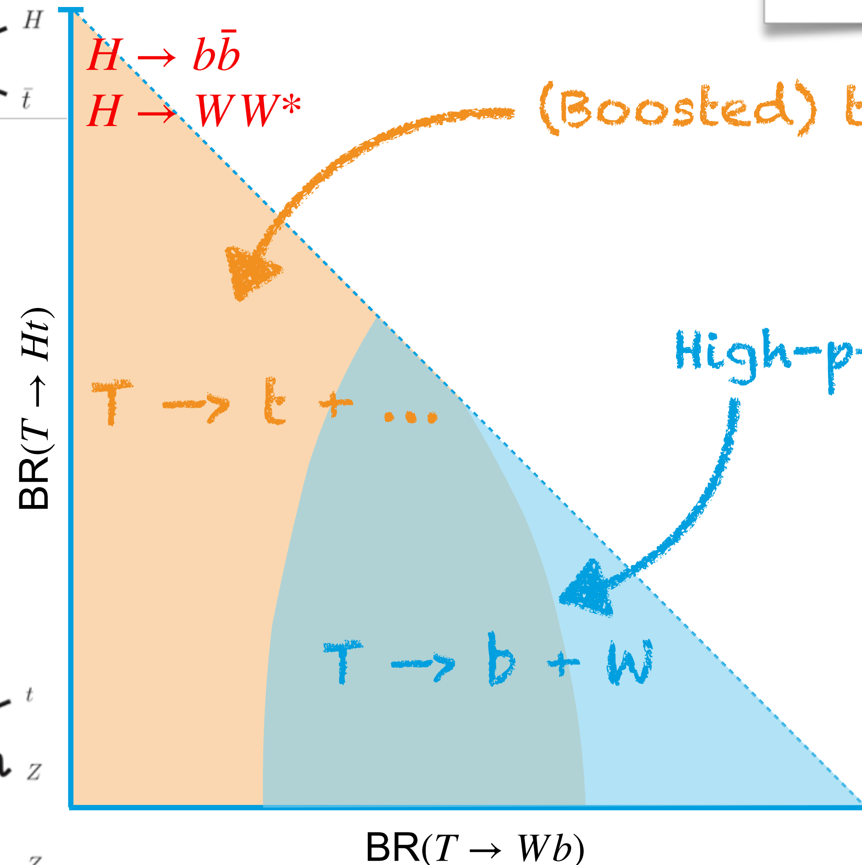

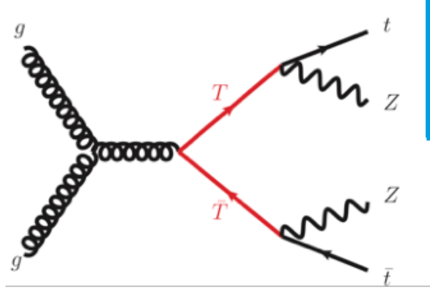

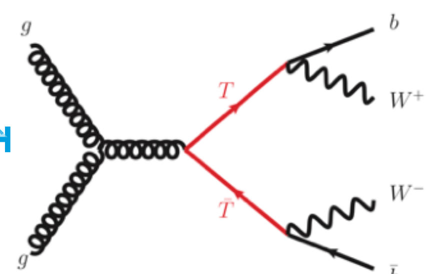

Pair-production searches

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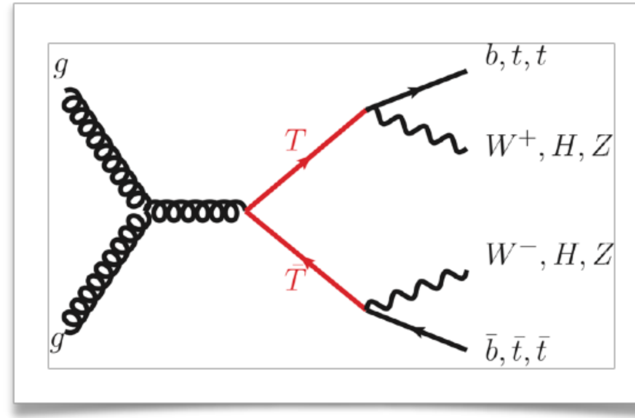

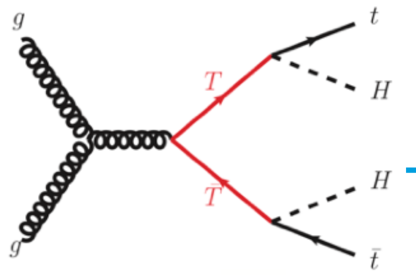

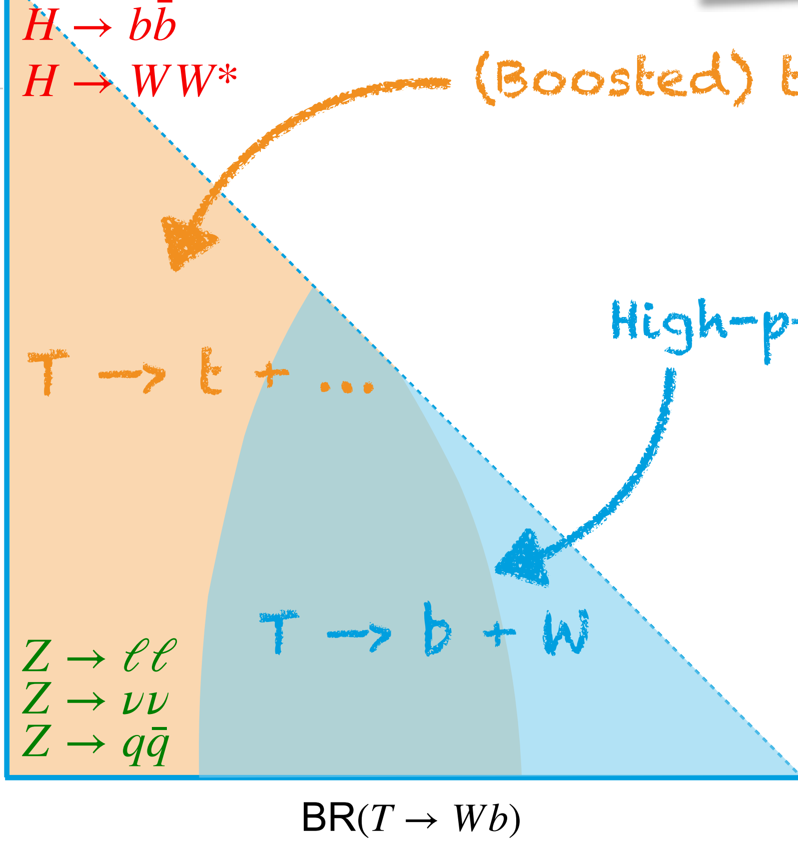

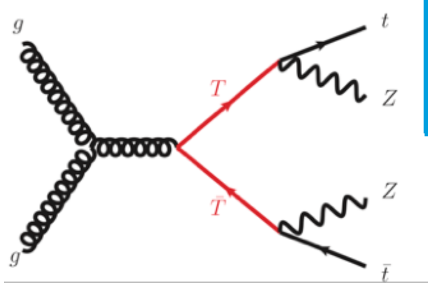

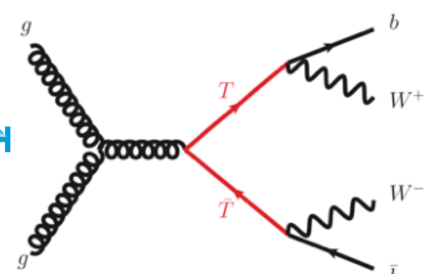

Pair-production searches

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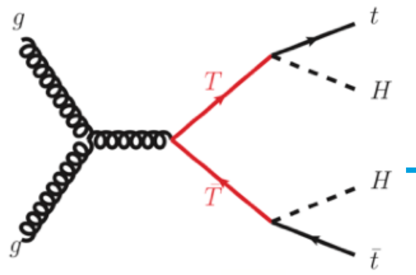
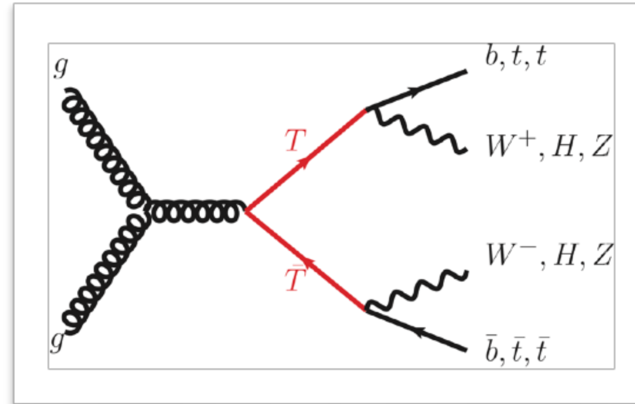
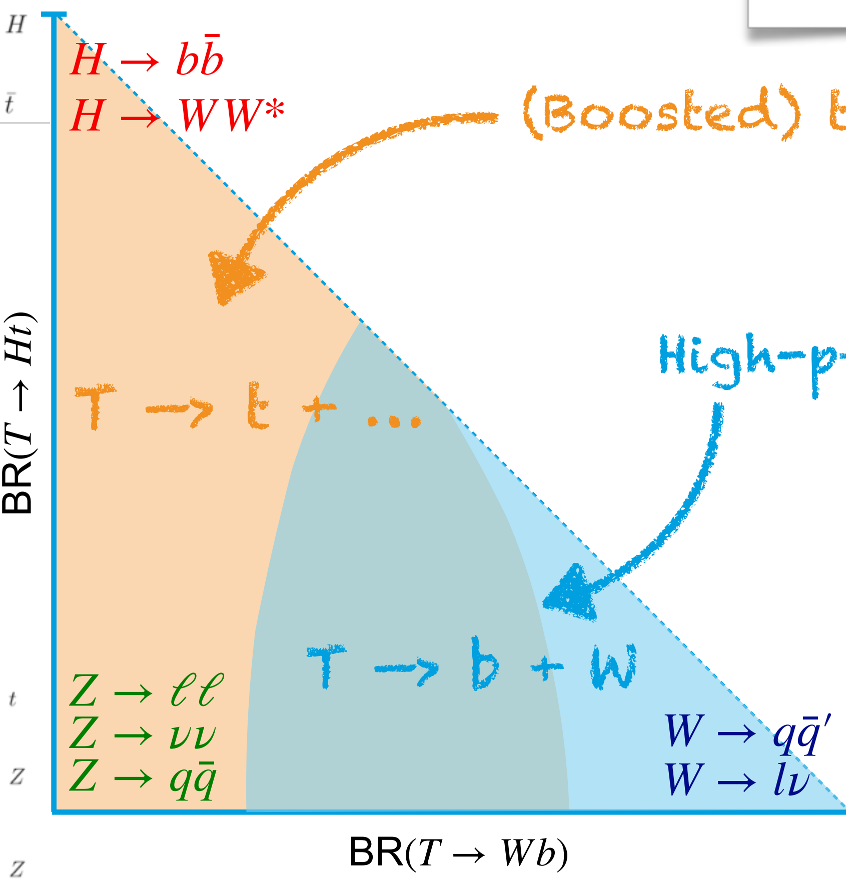
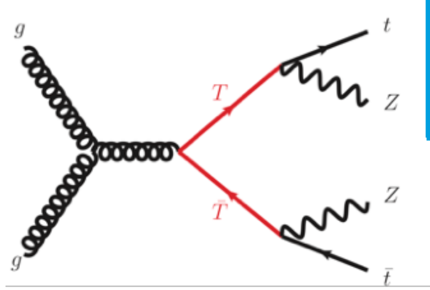
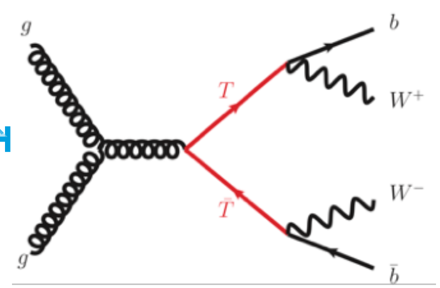








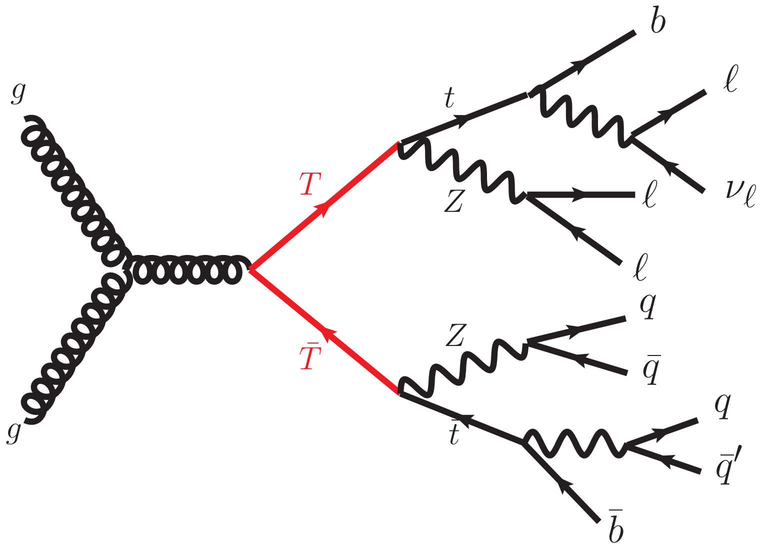


Pair-production searches

Signatures

Pair-production searches

Signatures



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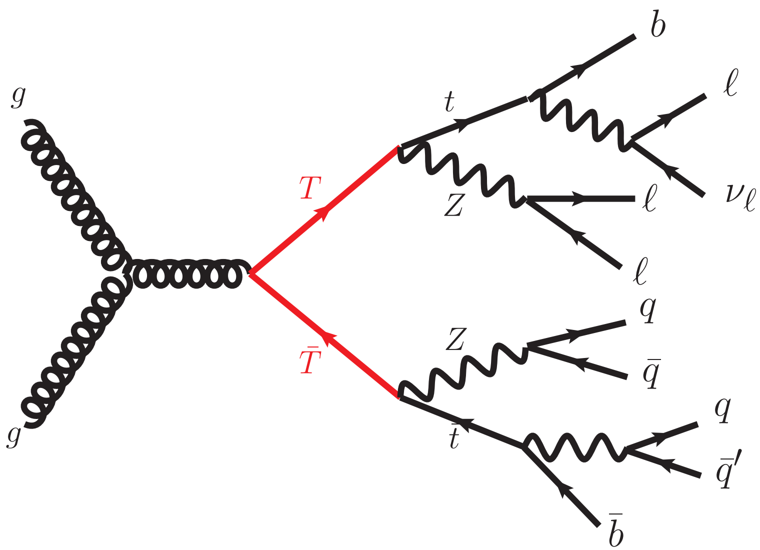

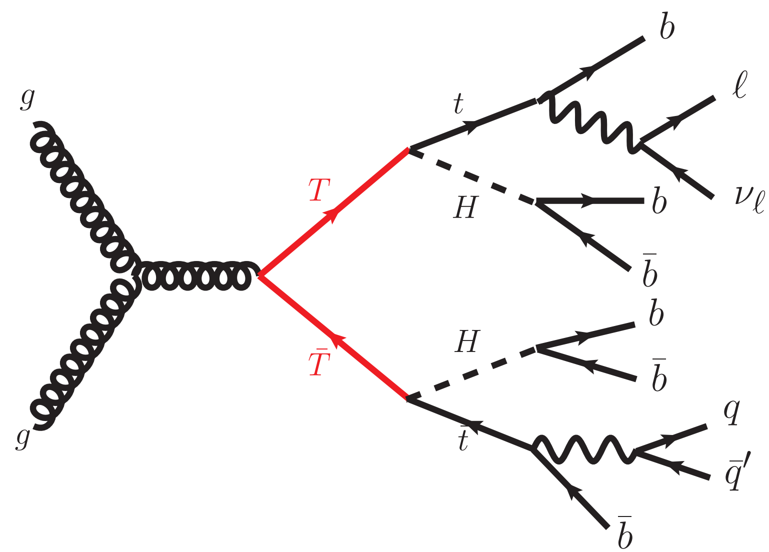

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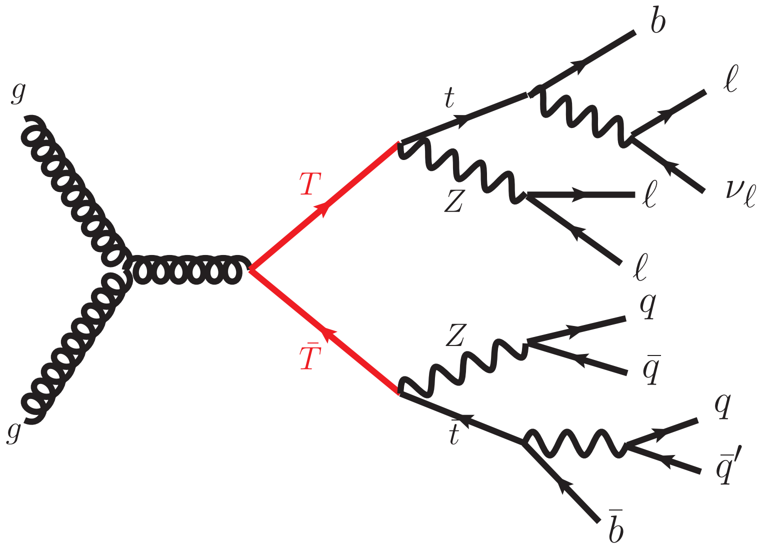

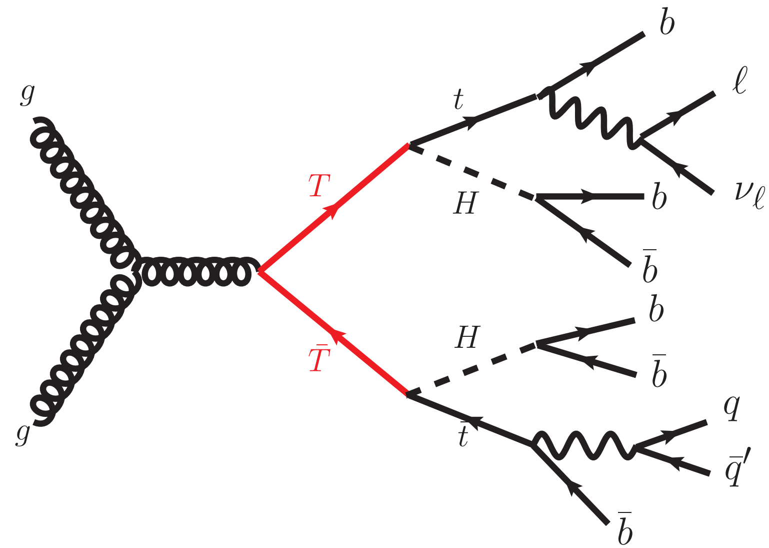

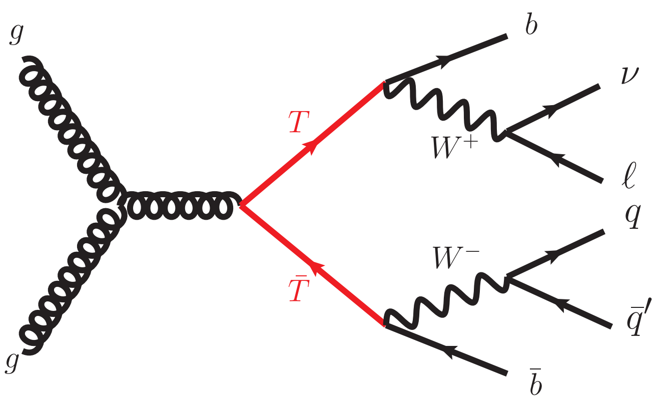

Pair-production searches

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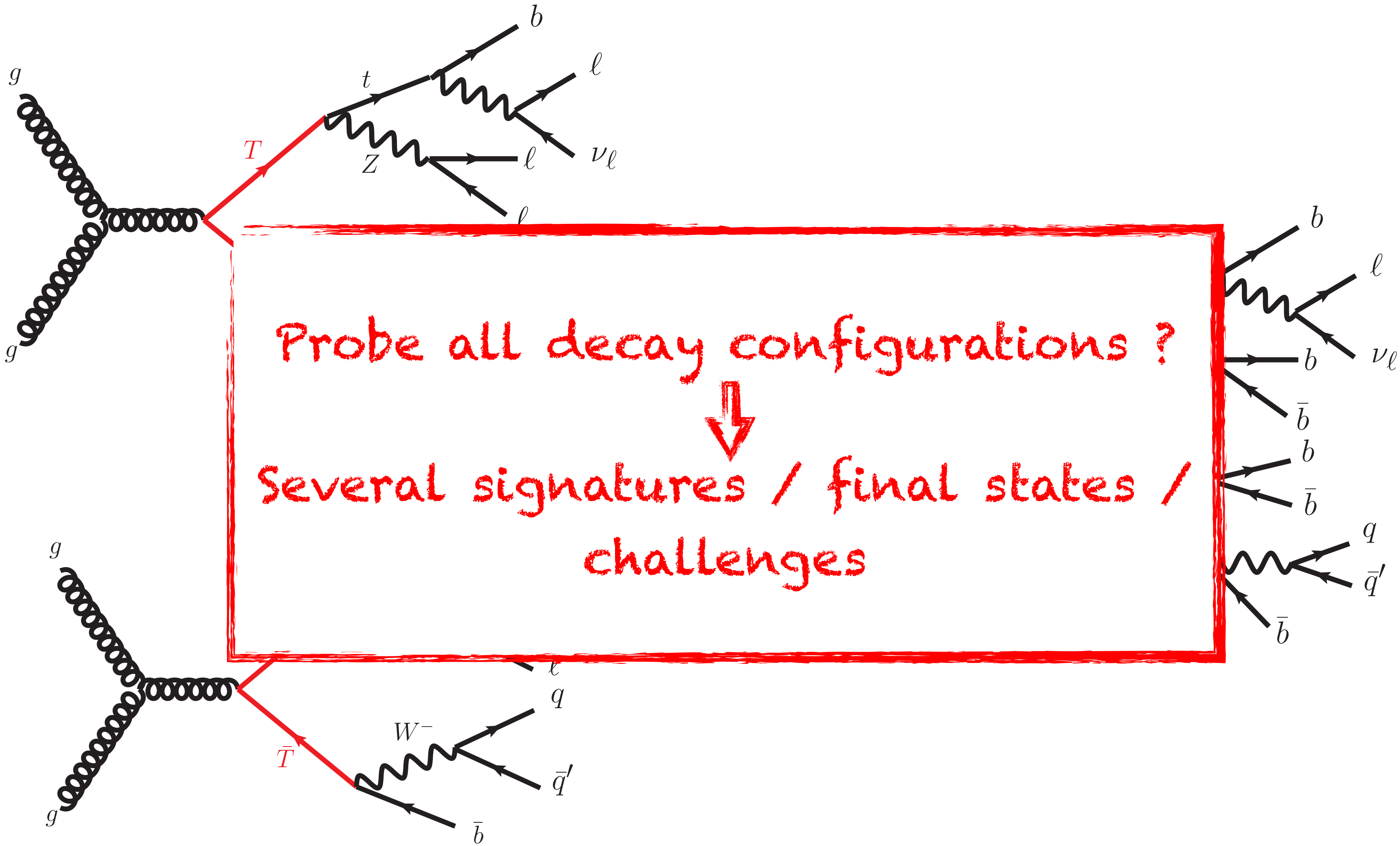
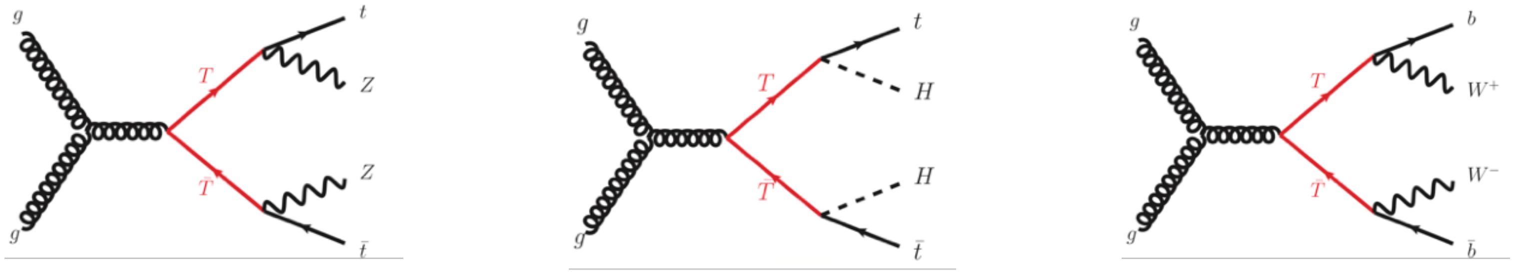


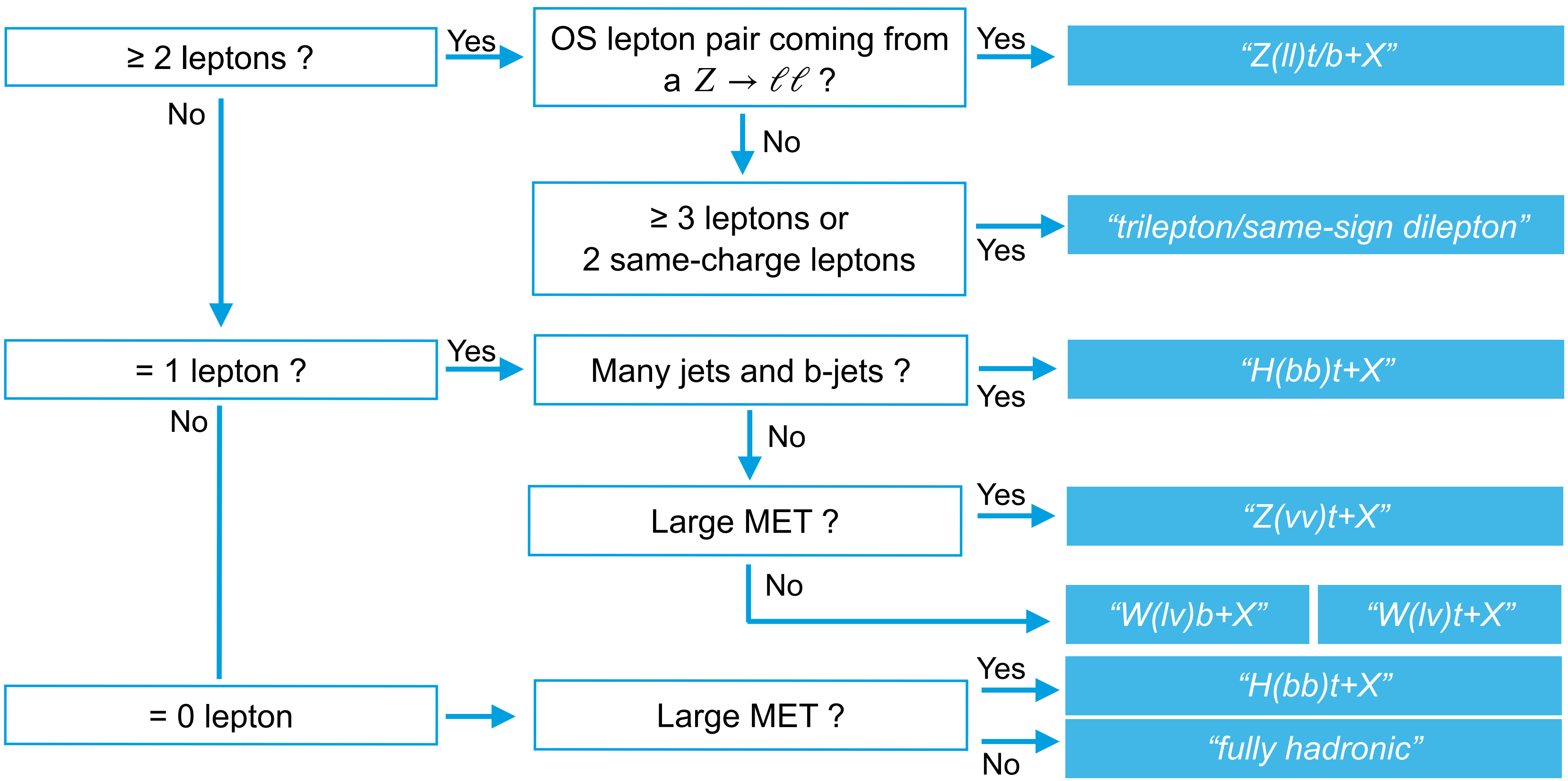
Probe all decay configurations ?

⇓

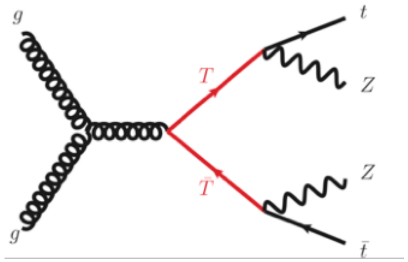
Several signatures / final states / challenges

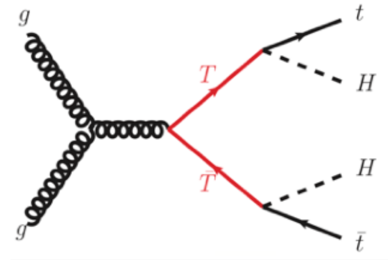
Pair-production searches

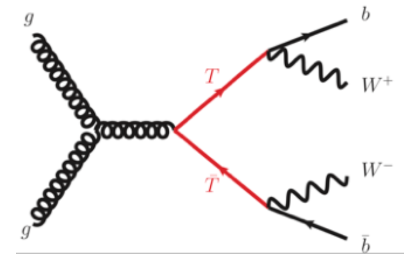




Pair-production searches





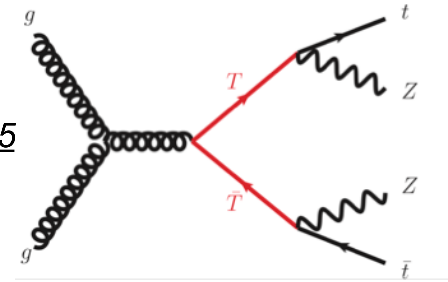


- ≥ 2 leptons ?
  - Yes → OS lepton pair coming from a $Z \to \ell\ell$?
    - Yes → "Z(ll)t/b+X"
    - No → ≥ 3 leptons or 2 same-charge leptons
      - Yes → "trilepton/same-sign dilepton"
  - No → = 1 lepton ?
    - Yes → Many jets and b-jets ?
      - Yes → "H(bb)t+X"
      - No → Large MET ?
        - Yes → "Z(νν)t+X"
        - No → "W(lν)b+X" | "W(lν)t+X"
    - No → = 0 lepton → Large MET ?
      - Yes → "H(bb)t+X"
      - No → "fully hadronic"

Pair-production searches

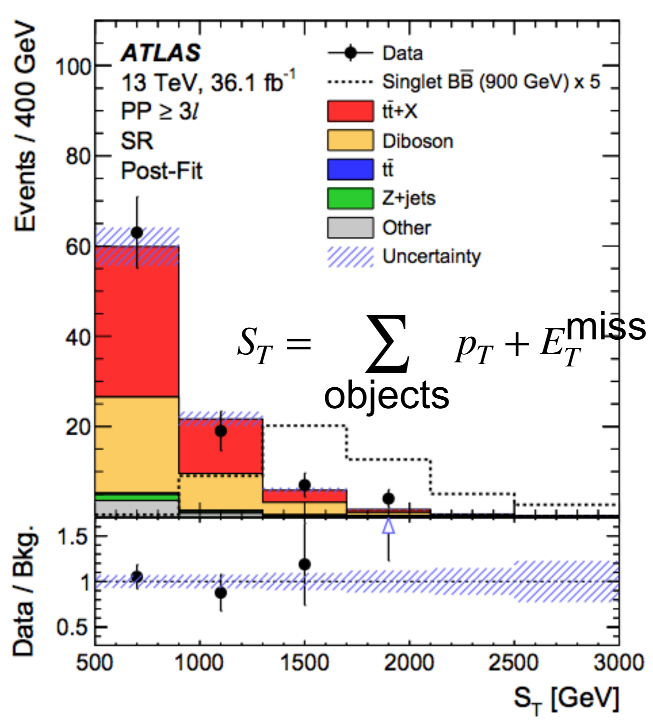
Z(ll)t/b+X

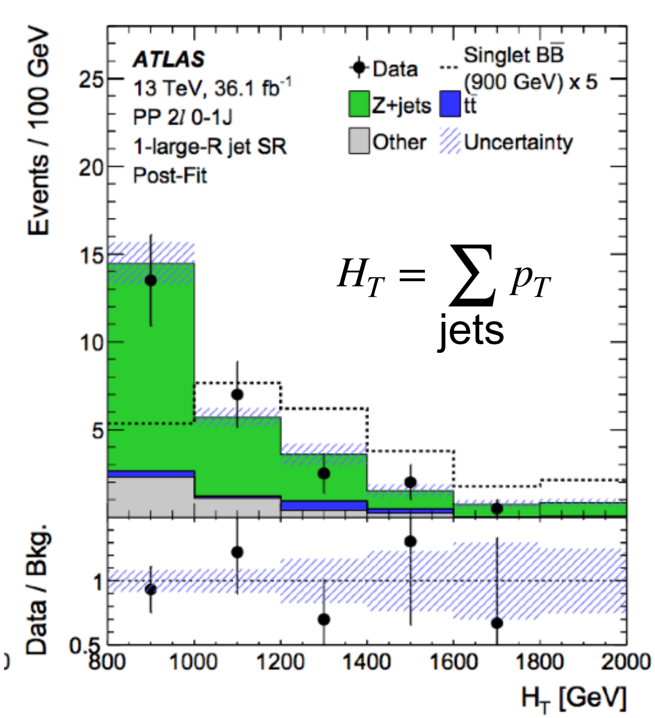
arXiv:1806.10555
Accepted by JHEP



- Selects **high-p$_T$** $Z \to \ell\ell$ events in dilepton / trilepton events
  - sub-channels depending on N_{leptons} and $N_{\text{boosted tops}}$ (4 signal regions)
  - 3-lepton channel: **most sensitive**
- **Main backgrounds**: $t\bar{t}$+V, diboson, depending on SR (calibrated in data)

Highest purity channel

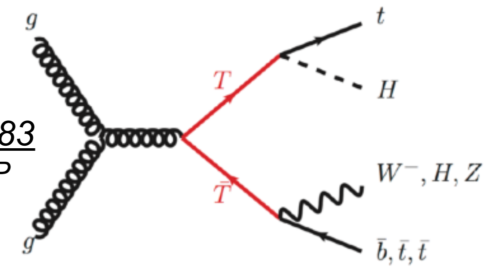




Pair-production searches

Same-sign leptons

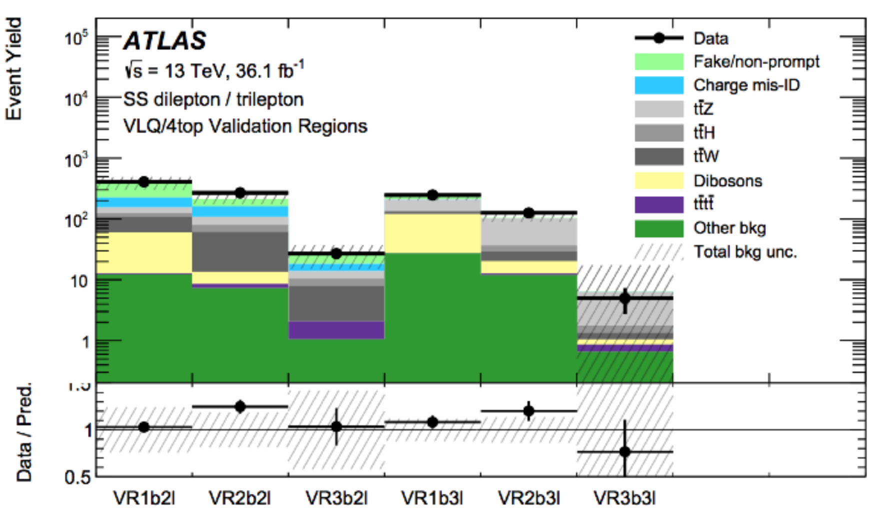
arXiv:1807.11883
Accepted by JHEP

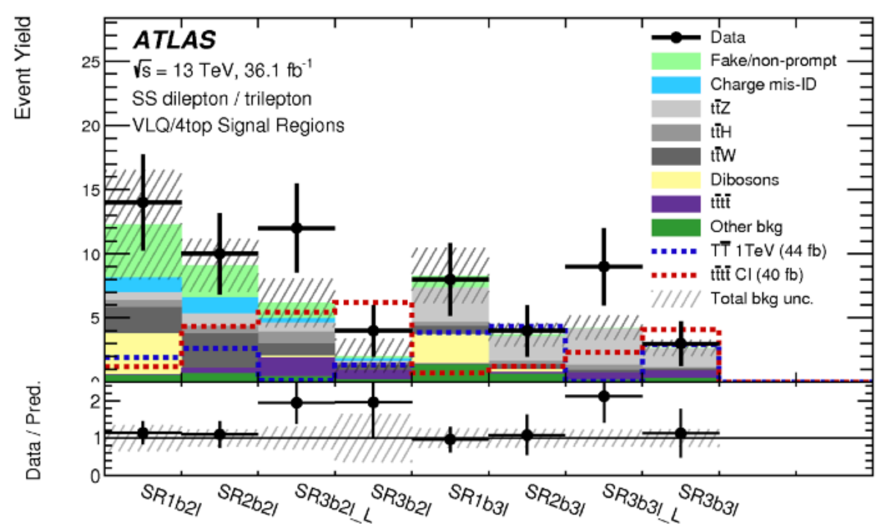


Background estimation

- Selects **same-sign dilepton** and non-Z **trilepton** events
  - typically from $T \to Ht \to WW^* \, t$ or $BB \to WtWt$ decays
  - signal regions: depending on $N_{leptons}$, $N_{b\text{-jets}}$, kinematic cuts

- **Main backgrounds**: fake/non-prompt leptons, charge mis-measurement, tt̄+V
  - validated in dedicated regions

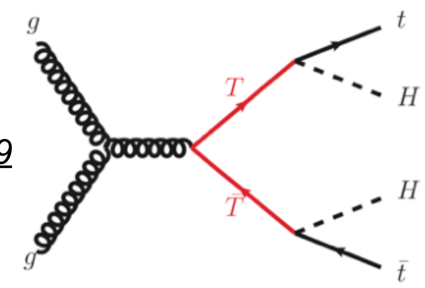




Pair-production searches

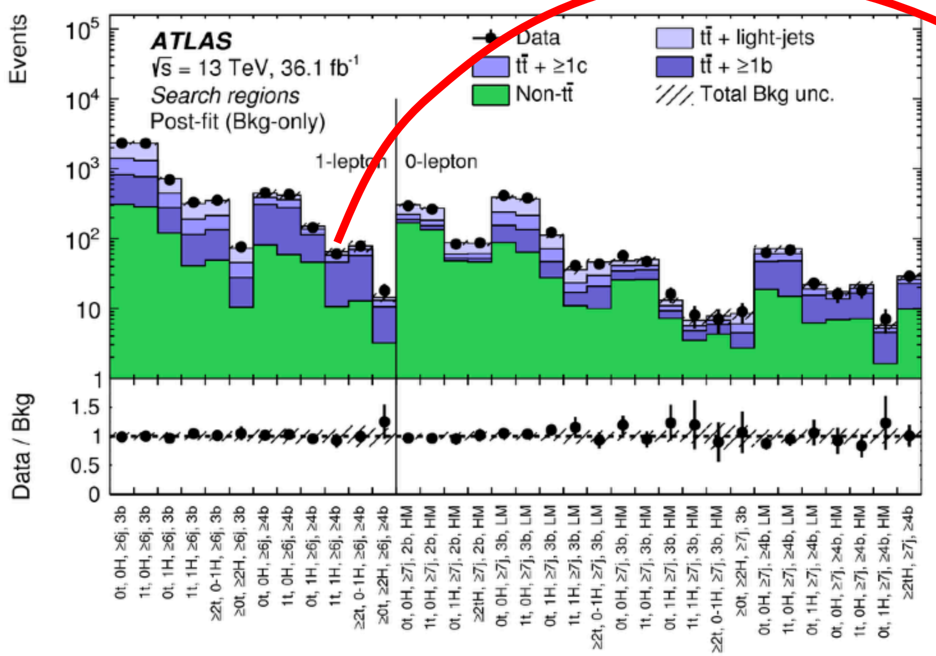
H(bb)t+X

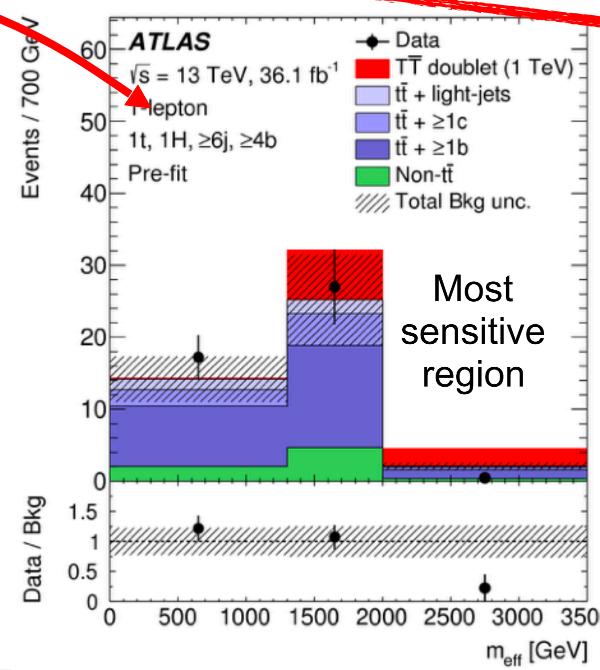
JHEP 07 (2018) 089



- Selects **high-p_T top quarks / Higgs bosons** in 1-lepton/0-lepton (high-MET) events
  - sub-channels depending on $N_{leptons}$, N_{tops}, N_{Higgs}, $N_{b\text{-jets}}$ (34 signal regions)
- **Main background:** $t\bar{t}$ + ≥1b (calibrated in data)

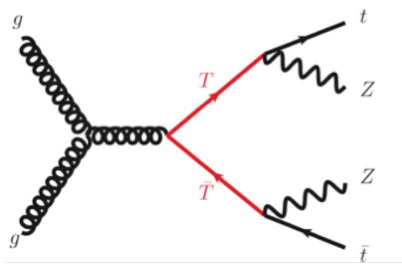
Background estimation

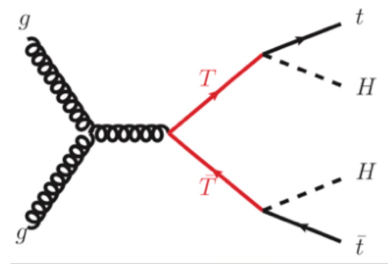


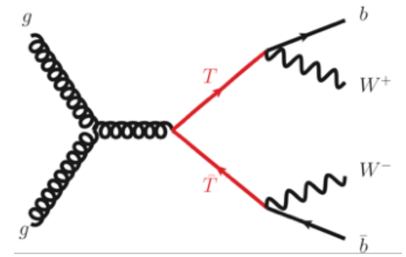


$$m_{\text{eff}} = \sum_{\text{objects}} p_T + E_T^{\text{miss}}$$

Pair-production searches







≥ 2 leptons ? → Yes → OS lepton pair coming from a $Z \to \ell\ell$? → Yes → "Z(ll)t/b+X"

OS lepton pair coming from a $Z \to \ell\ell$? → No → 3 leptons or 2 same-charge leptons → Yes → "trilepton/same-sign dilepton"

≥ 2 leptons ? → No → = 1 lepton ? → Yes → Many jets and b-jets ? → Yes → "H(bb)t+X"

Many jets and b-jets ? → No → Large MET ? → Yes → "Z(νν)t+X"

Large MET ? → No → "W(lν)b+X" | "W(lν)t+X"

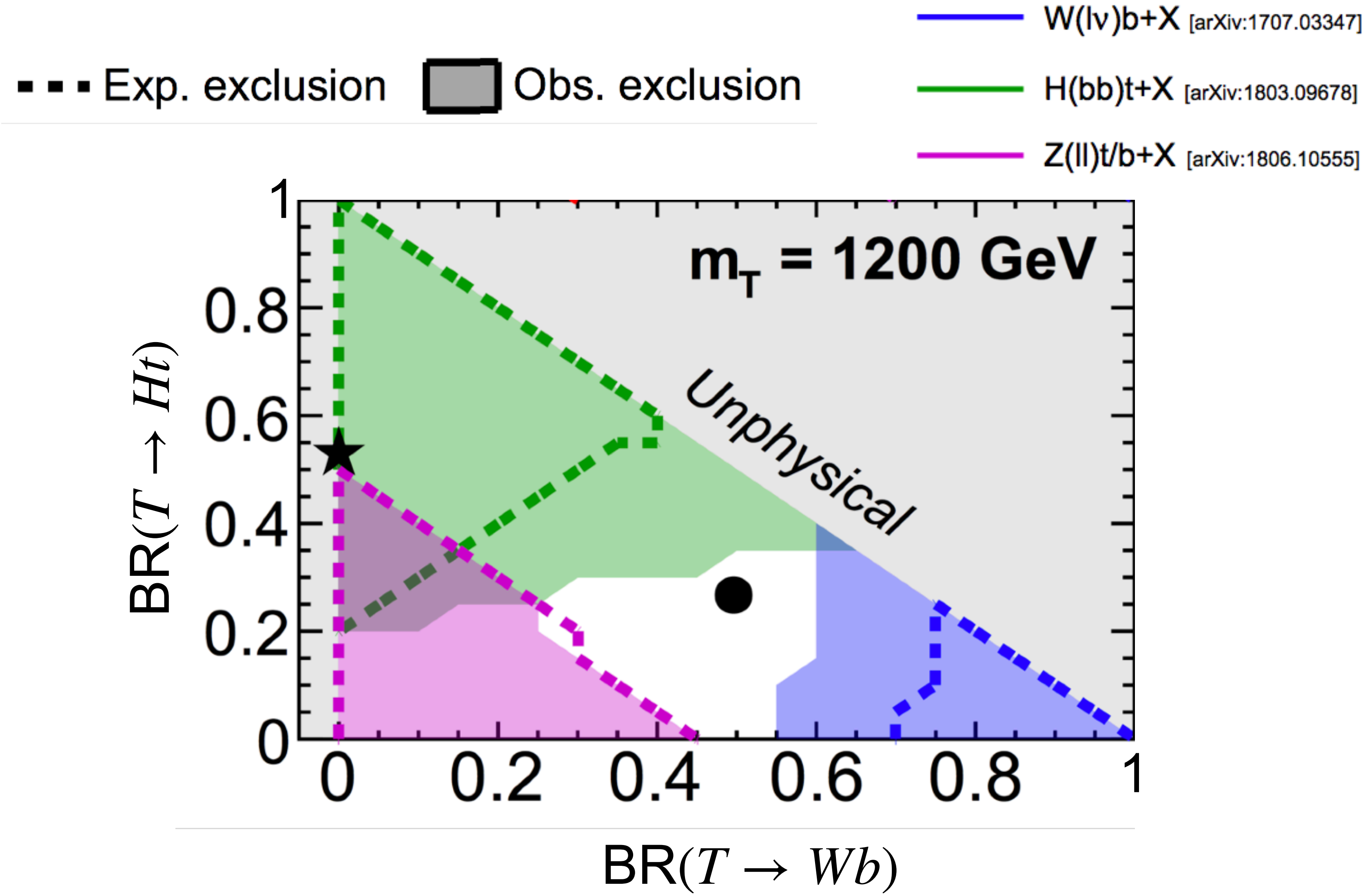
= 1 lepton ? → No → = 0 lepton → Large MET ? → Yes → "H(bb)t+X"

Large MET ? → No → "fully hadronic"

Pair-production searches

Phys. Rev. Lett. 121 (2018) 211801

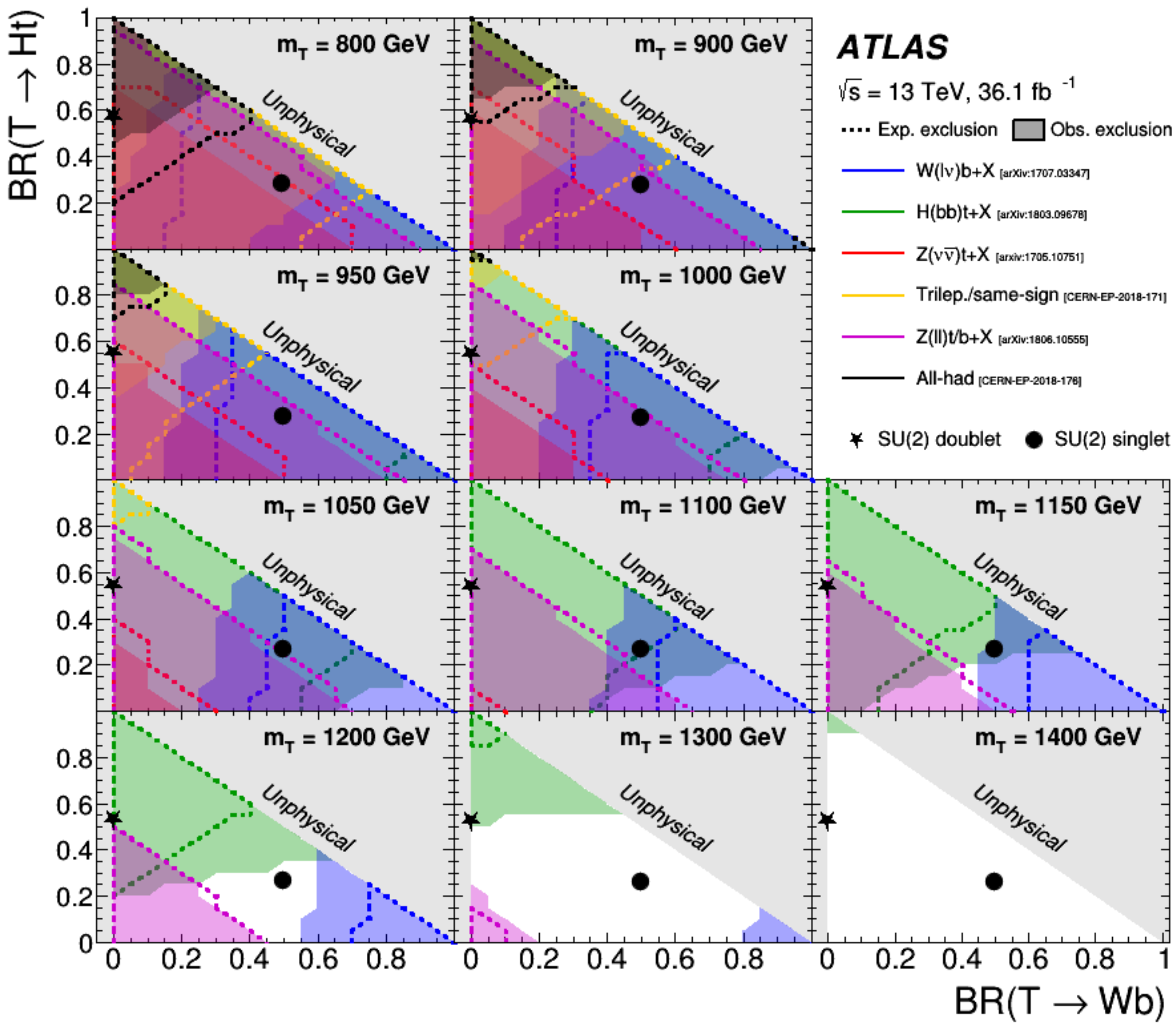
Sensitivity



Pair-production searches

Phys. Rev. Lett. 121 (2018) 211801

Summary plots



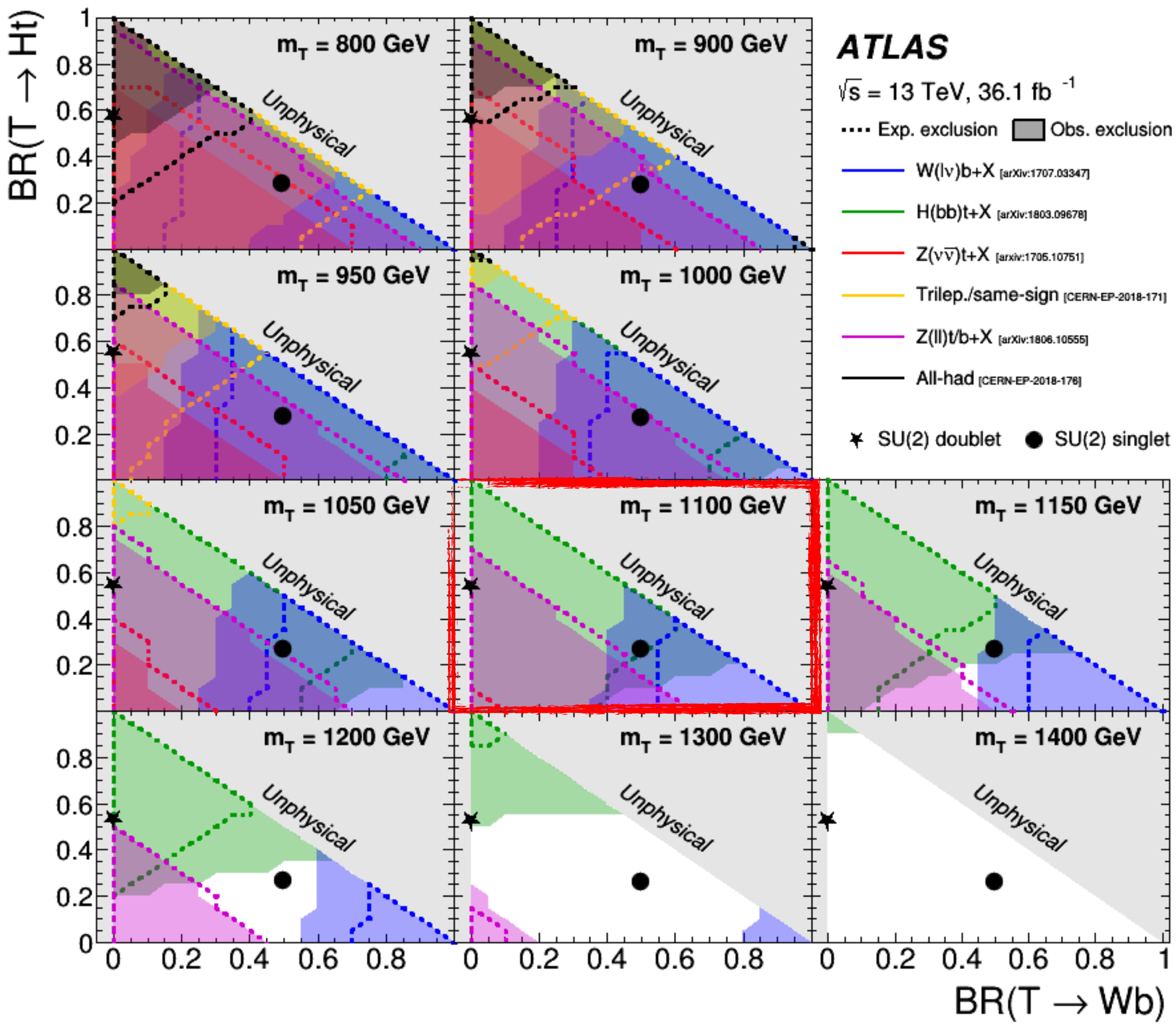
- **Excellent complementarity** between analyses: most parameter space “covered”
- **Non-overlapping** analyses

➔ **combined interpretation !**

Pair-production searches

Phys. Rev. Lett. 121 (2018) 211801

Summary plots



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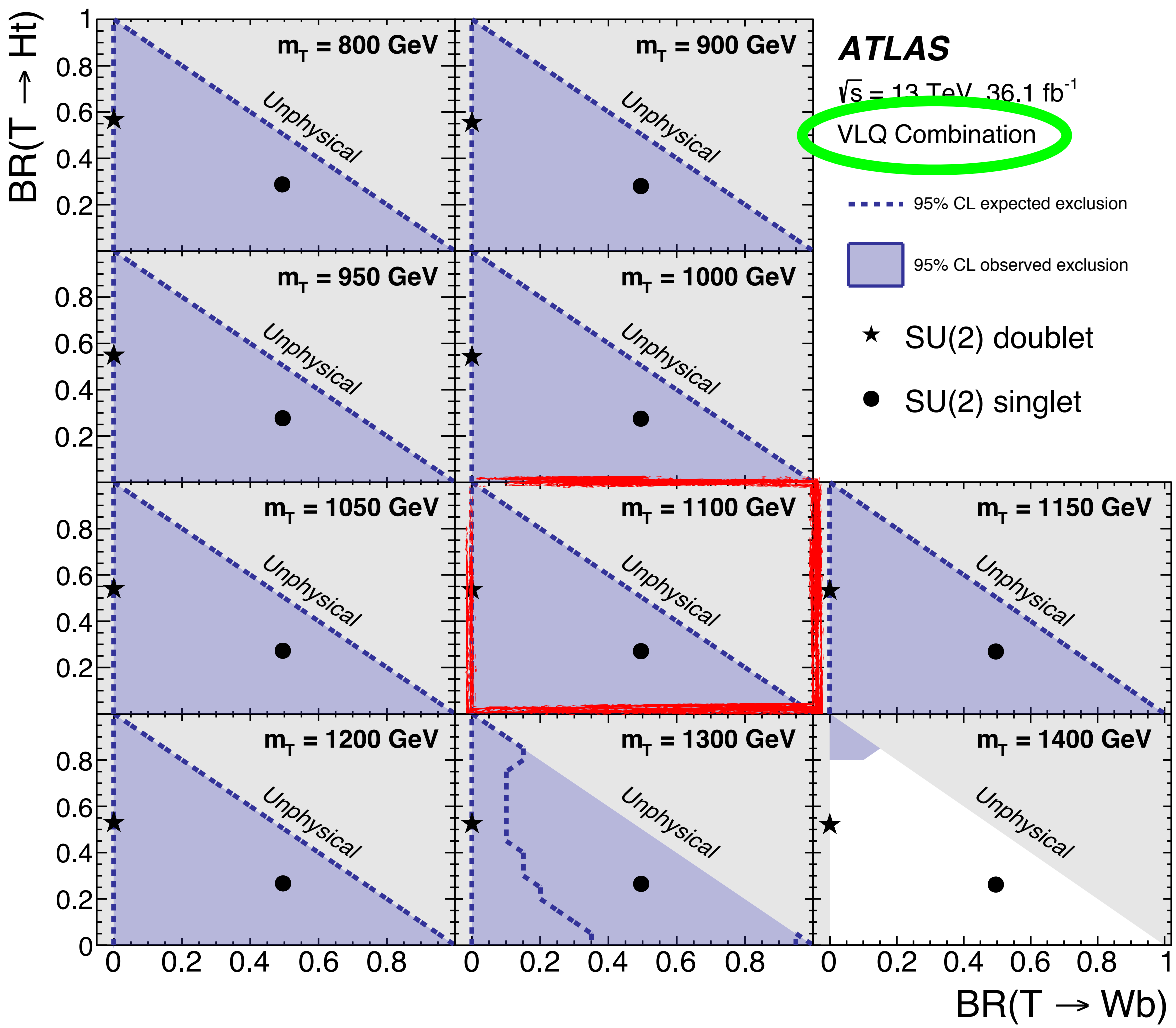
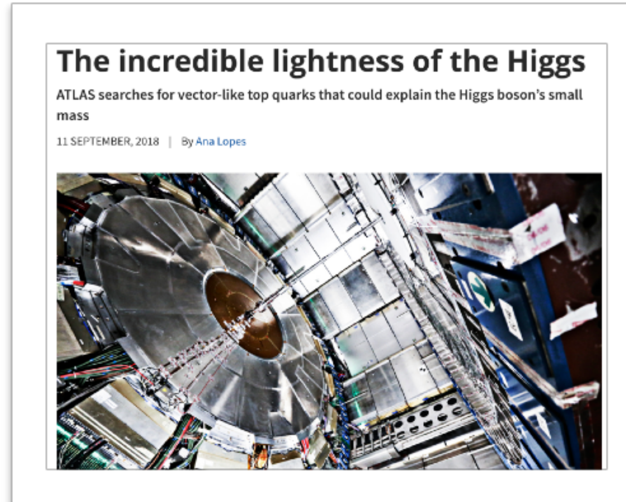
Pair-production searches

Combination

Phys. Rev. Lett. 121 (2018) 211801

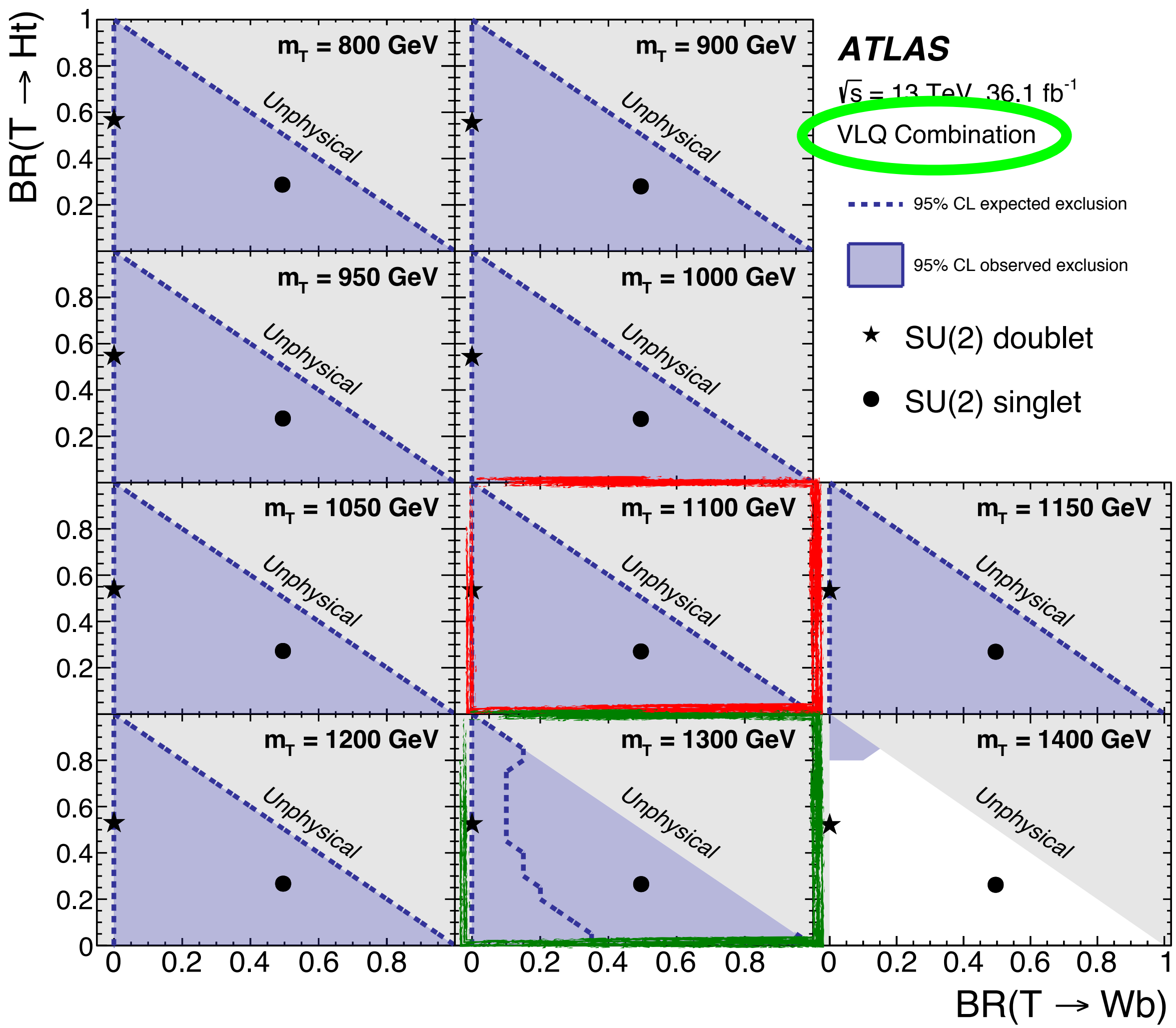




Pair-production searches

Combination

Phys. Rev. Lett. 121 (2018) 211801



The incredible lightness of the Higgs

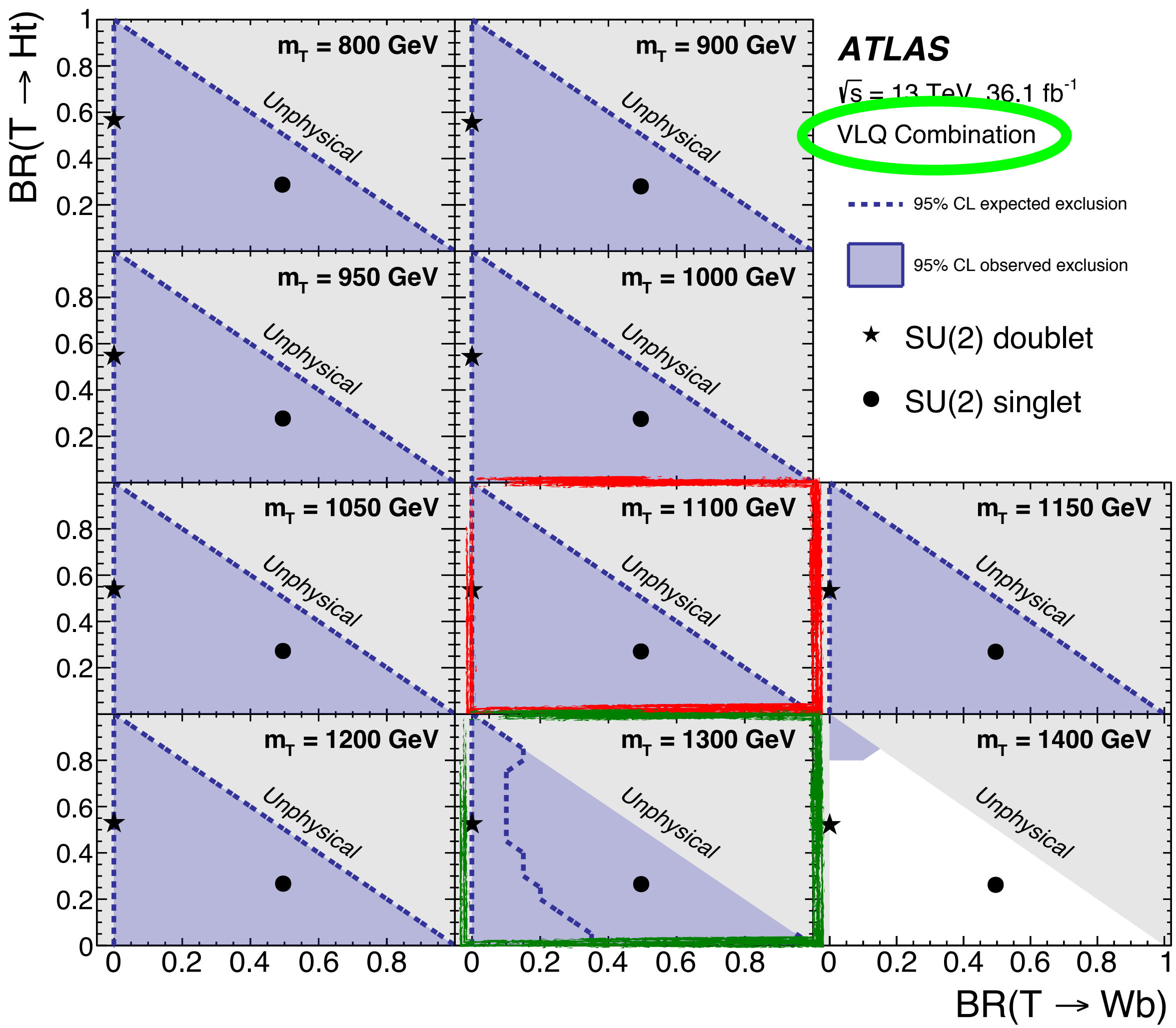
ATLAS searches for vector-like top quarks that could explain the Higgs boson's small mass

11 SEPTEMBER, 2018 | By Ana Lopes

Pair-production searches

Phys. Rev. Lett. 121 (2018) 211801

Combination



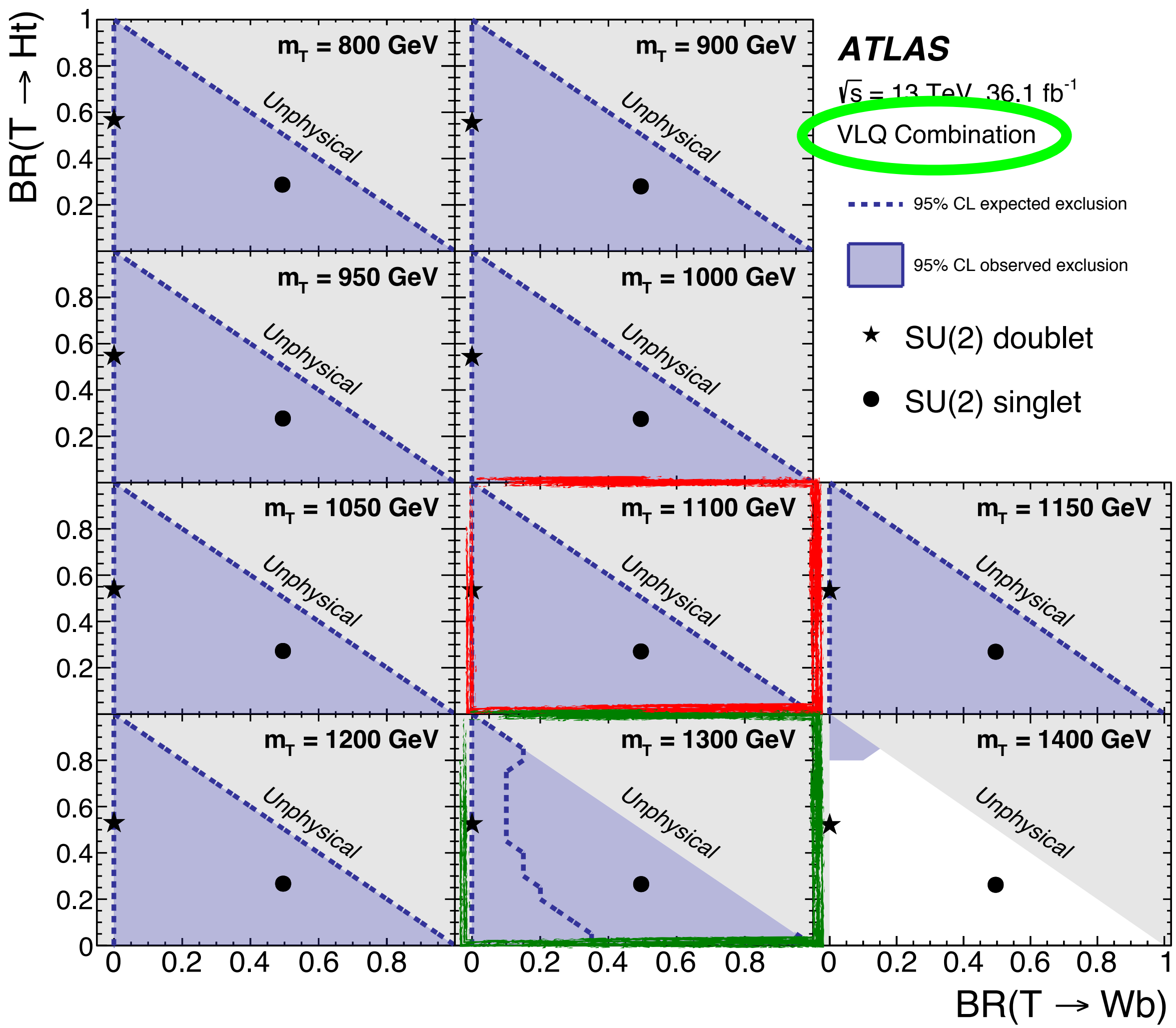
Strong sensitivity gain !

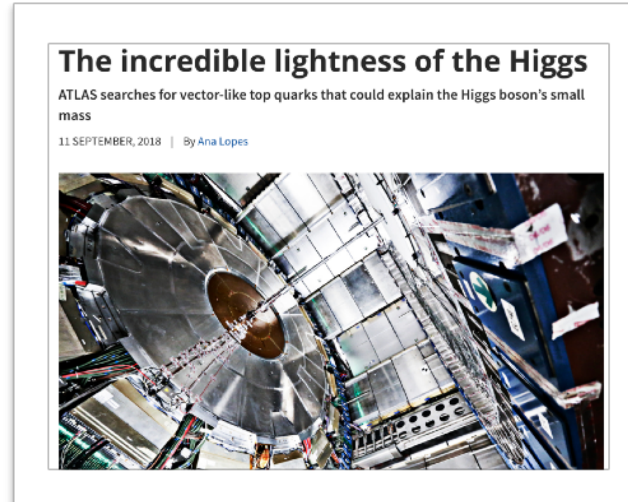
=> No evidence for low-mass VLQs

Pair-production searches

Phys. Rev. Lett. 121 (2018) 211801

Combination





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Strong sensitivity gain !

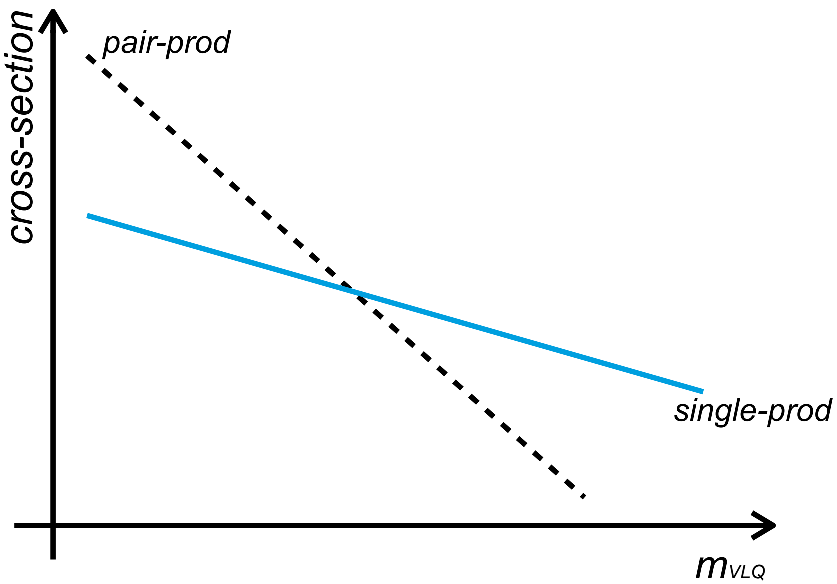
=> No evidence for low-mass VLQs

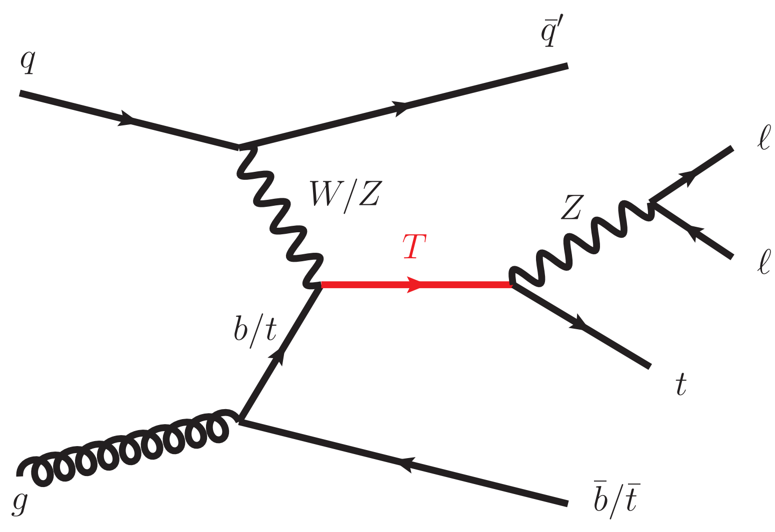
Look for high mass VLQ: single-production !

Single-production searches

Topologies

- Single production possibly **more important for high VLQ masses**
- Cross-section depends on **VLQ coupling to SM particles**





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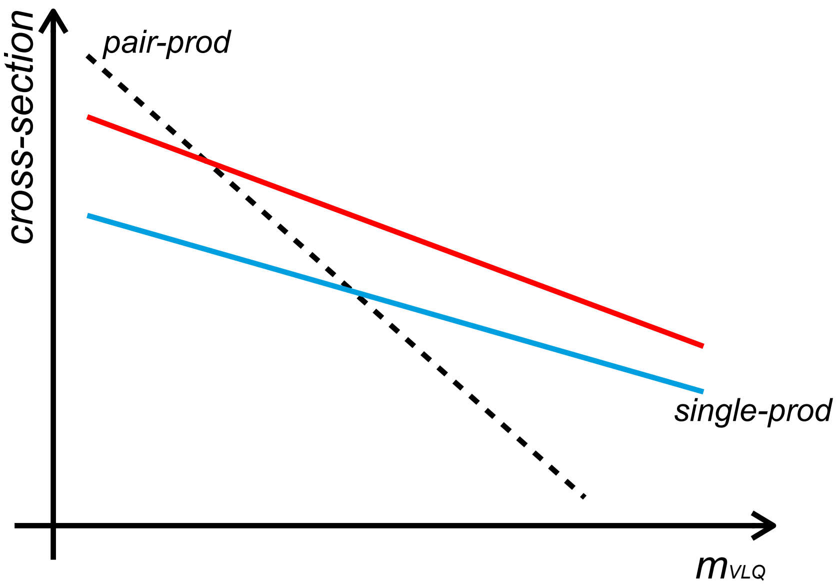

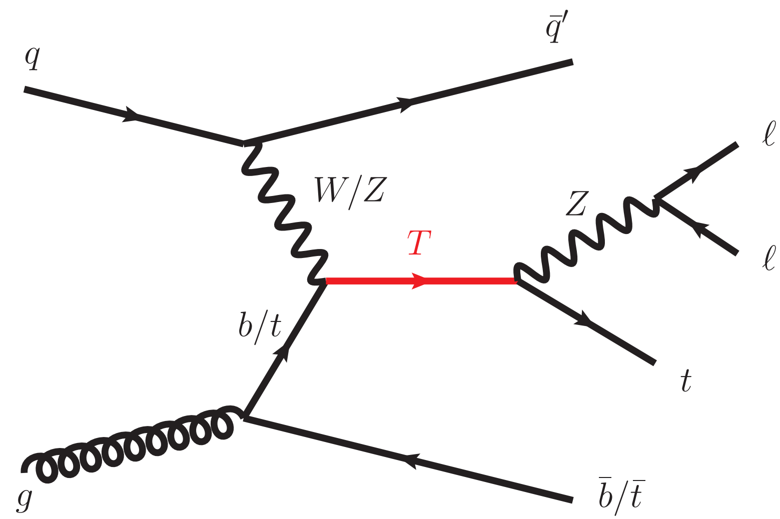

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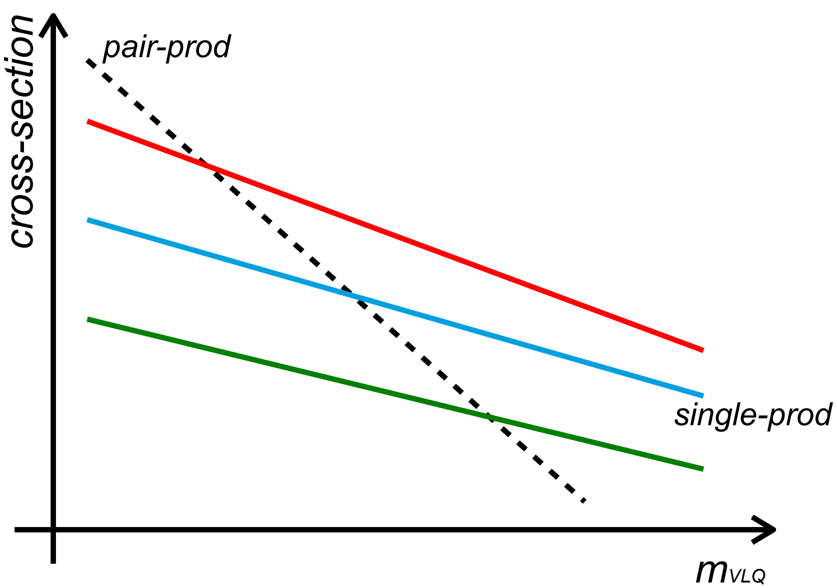
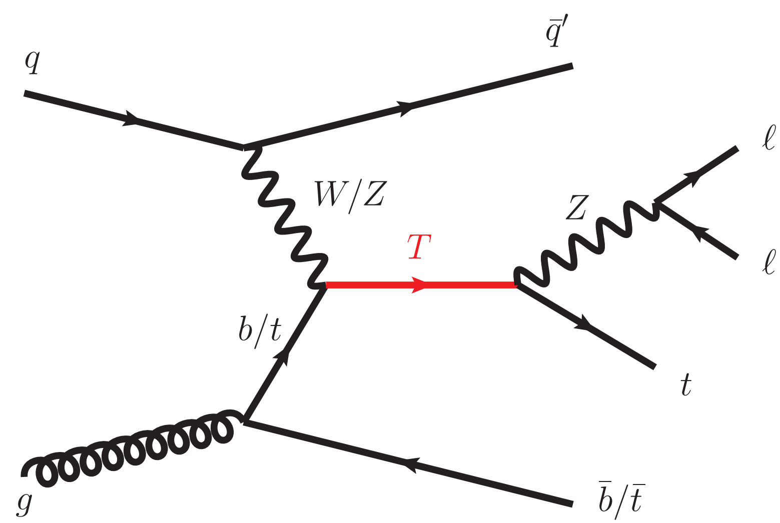
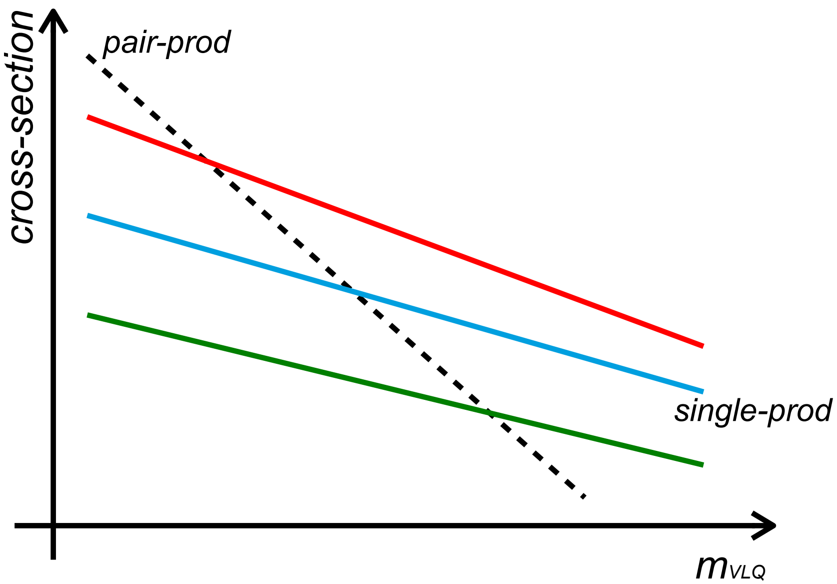


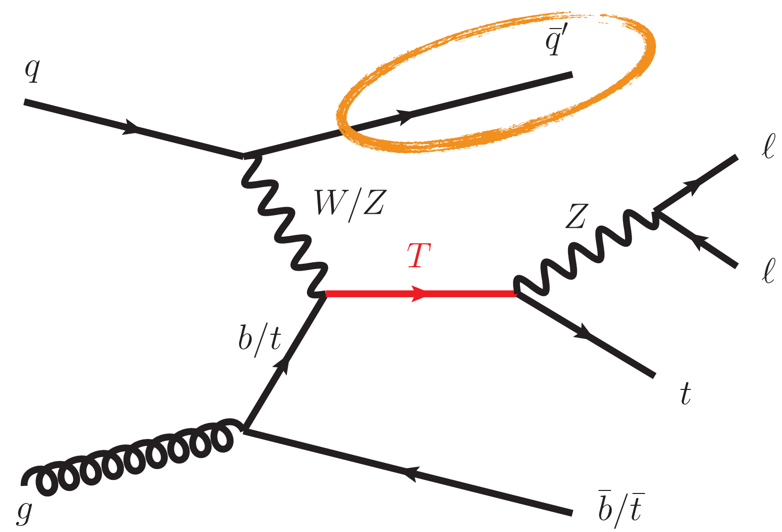


Single-production searches

Topologies

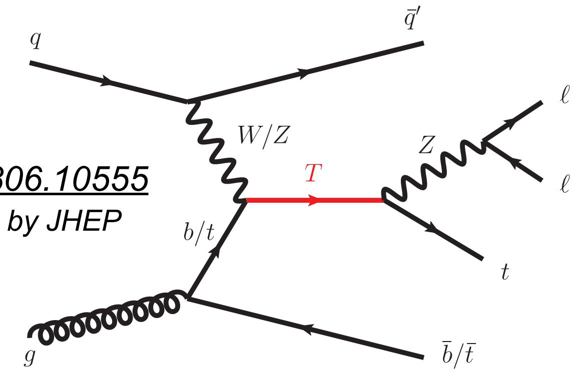
- Single production possibly **more important for high VLQ masses**
- Cross-section depends on **VLQ coupling to SM particles**
- **Event properties** different wrt pair-production
  - Less busy final state **but forward jet**





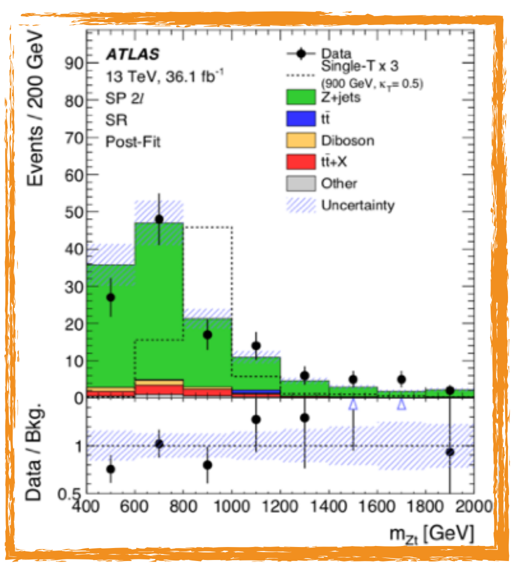
Single-production searches

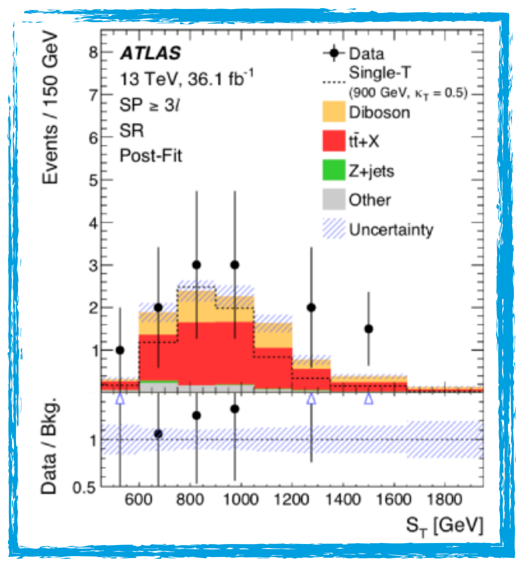
Single $T/B \to Z(\ell\ell)t/b$



arXiv:1806.10555
Accepted by JHEP

- Selects **high-p$_T$** $Z \to \ell\ell$ events
    - *dilepton*: presence of a **top-tagged jet** → **full VLQ reconstruction**
    - *trilepton*: ambiguity in reconstruction → **use kinematic variable**
- Main background: Z+jets or $t\bar{t}$+V

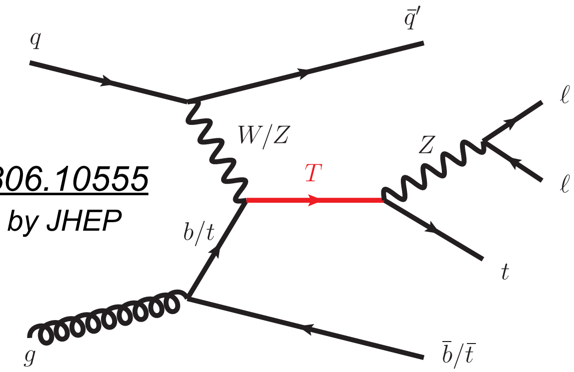




$$S_T = \sum_{\text{objects}} p_T + E_T^{\text{miss}}$$

Single-production searches

Single $T/B \to Z(\ell\ell)t/b$



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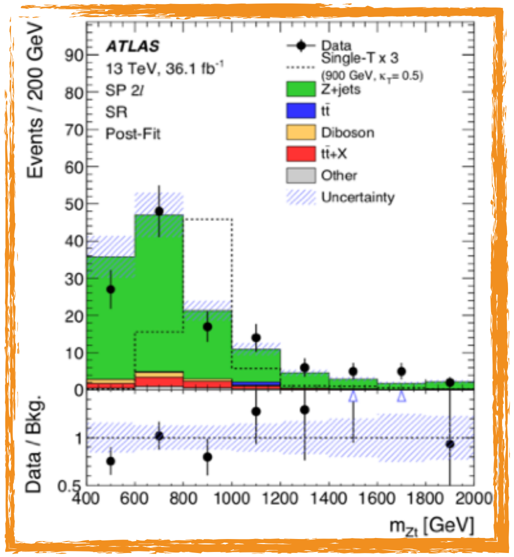
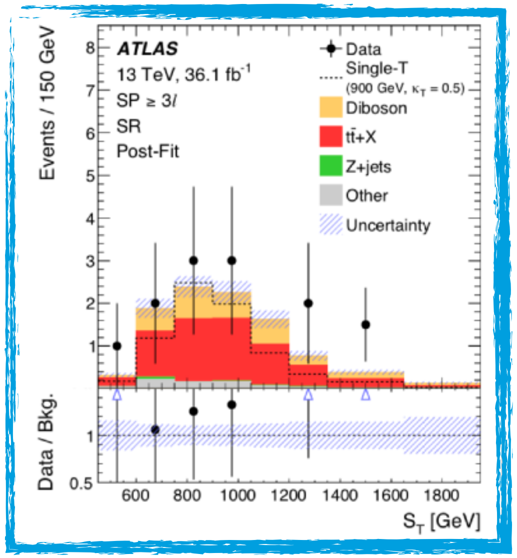
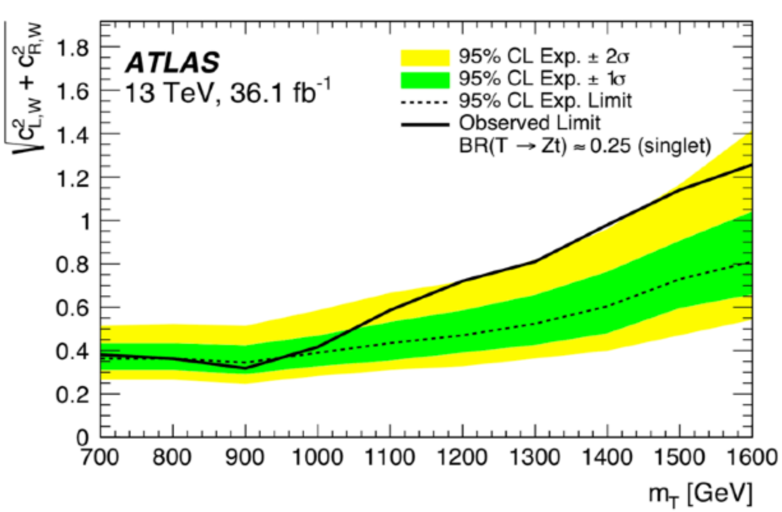
- Main background: Z+jets or $t\bar{t}$+V
- Limits set for variable coupling assumptions → **model-independent interpretation**







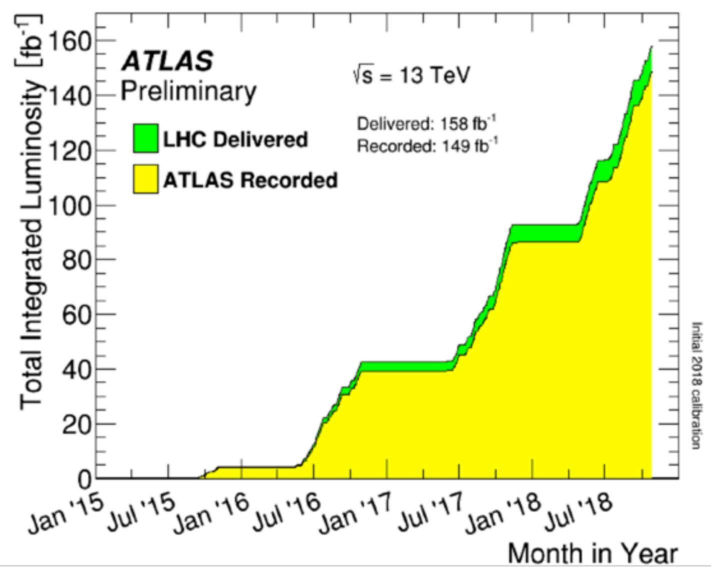
$$S_T = \sum_{\text{objects}} p_T + E_T^{\text{miss}}$$

VLQ searches: next steps ?

- For all VLQ searches: sensitivity **limited by statistics**
- Excellent coverage in **pair-production** → low-mass VLQs strongly constrained
  - Combination significantly extends sensitivity !
- Single-production **more and more relevant**: several studies underway !
  - Quite challenging to interpret in a “model-independent” manner
- More complete models ? Exotics decays ?

Summary

- Top quark: ideal to **probe several new theories extending Standard Model**
- **Heavy resonances** decaying to top quarks and **vector-like quarks**
  - Thoroughly searched for by ATLAS in several (new) channels
  - Challenging experimental final states
  - No signs of new particles (yet) → strong **constraints** on many BSM theories
- Sensitivity mostly **limited by statistics**
  - Will benefit from new data coming from LHC …
  - … and increase of signal acceptance !
- **Stay tuned for full Run 2 results !**



Thank you

Contact

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ATLAS
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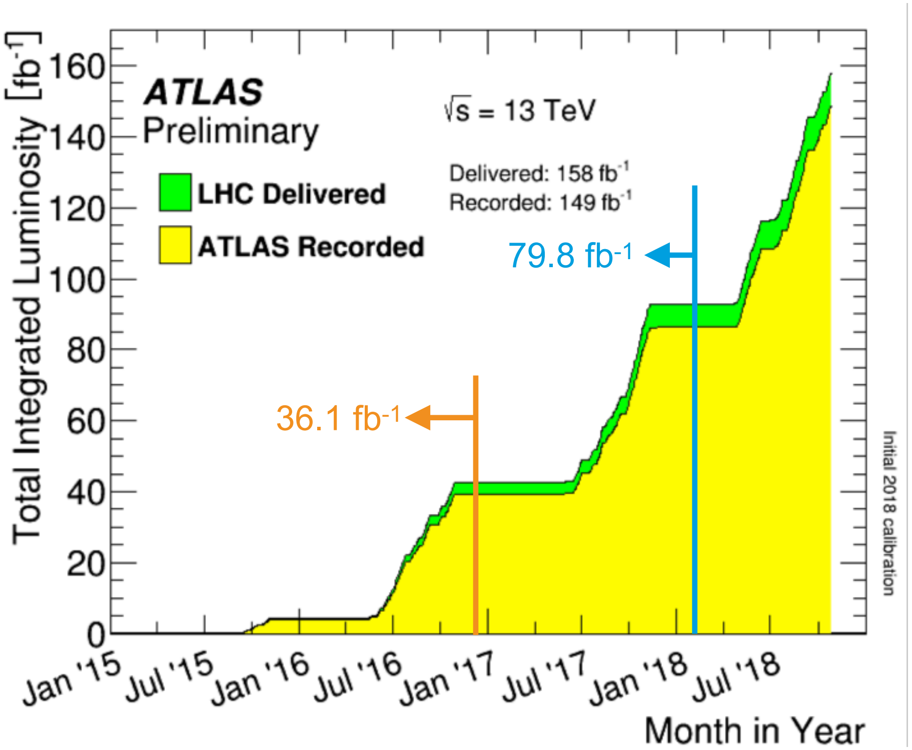
Backup

LHC and luminosity

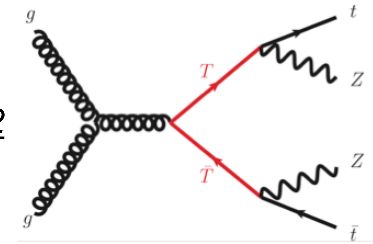
- New Physics events: **rare** and at **high energy**
- Searches using **Run 2 LHC data**
  - Centre-of-mass energy: $\sqrt{s}$ = 13 TeV
  - Luminosity: 36.1 fb^{-1} or 79.8 fb^{-1}



Pair-production searches

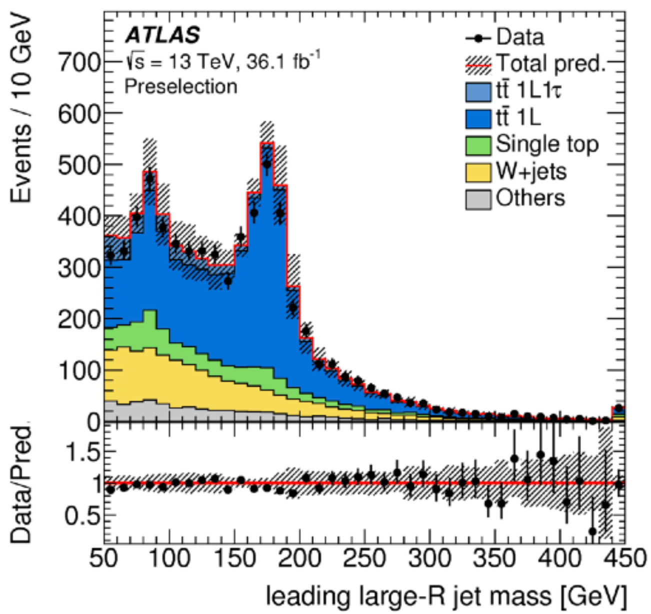
Z(νν)t+X

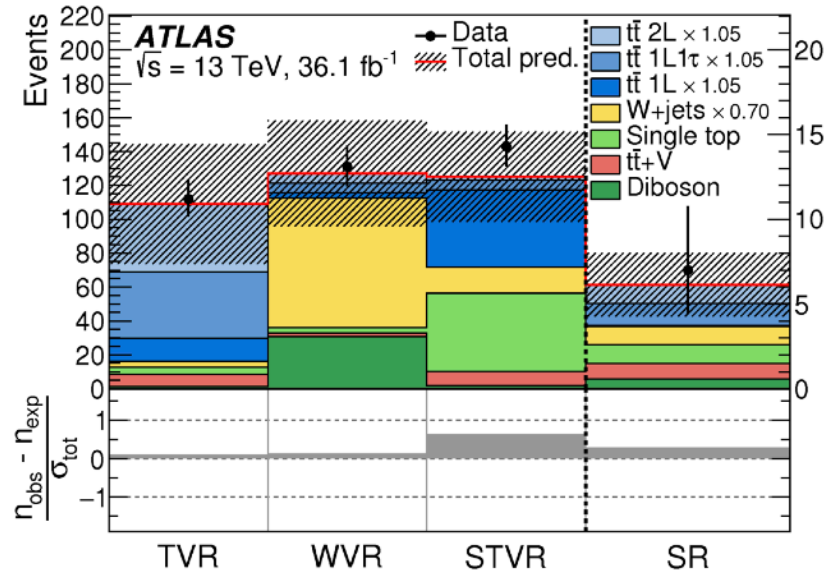
JHEP 08 (2017) 052



Hadronic top identification

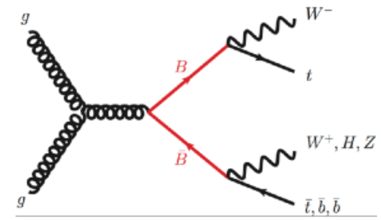
- Selects 1-lepton events with **large MET**
  - Selecting $T \to Z(\nu\nu)t$ events
  - **Jet-reclustering** to identify boosted top quarks
- **Main backgrounds**: top background and W+jets (calibrated in data)



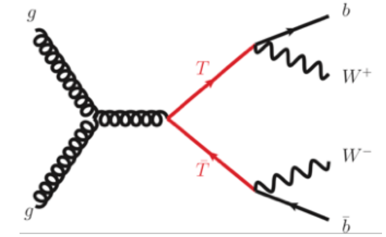


Pair-production searches

Wb/t+X



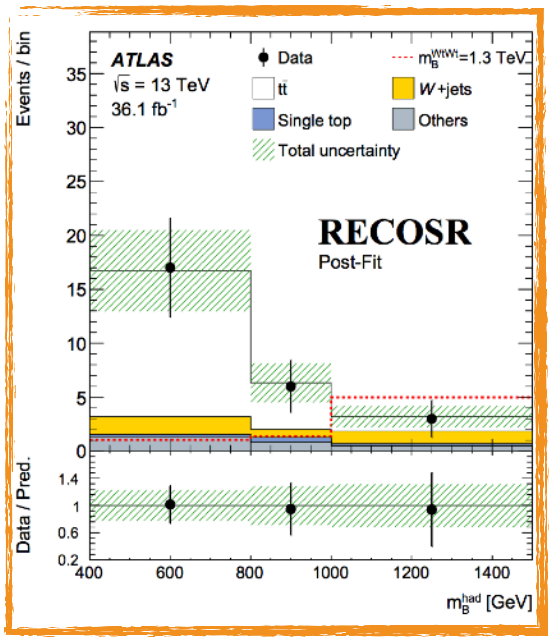
JHEP 08 (2018) 048

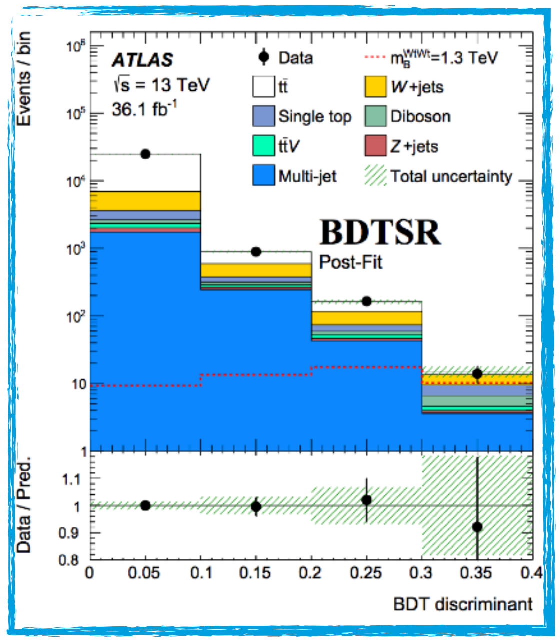


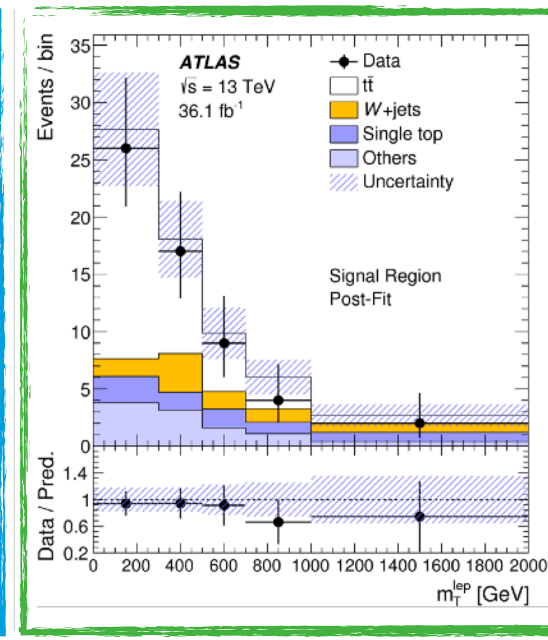
JHEP 10 (2017) 141

- Select 1-lepton events with **high-p_T hadronic W bosons**
  - BB → Wt+X: complex final state → **full reconstruction** otherwise **MVA strategy**
  - TT → Wb+X: reconstruct $T \rightarrow Wb \rightarrow l\nu b$ mass
- **Main background**: $t\bar{t}$ (calibrated in data)

Event reconstruction



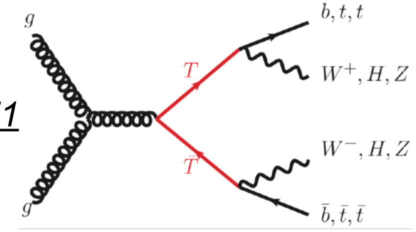




Pair-production searches

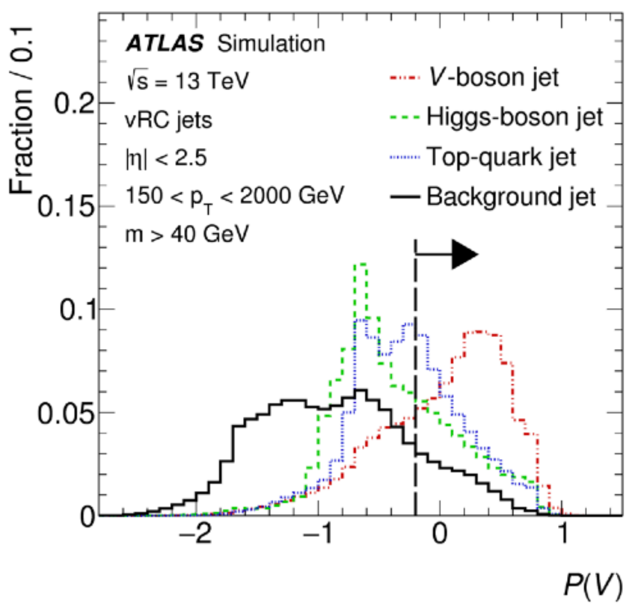
Fully-hadronic

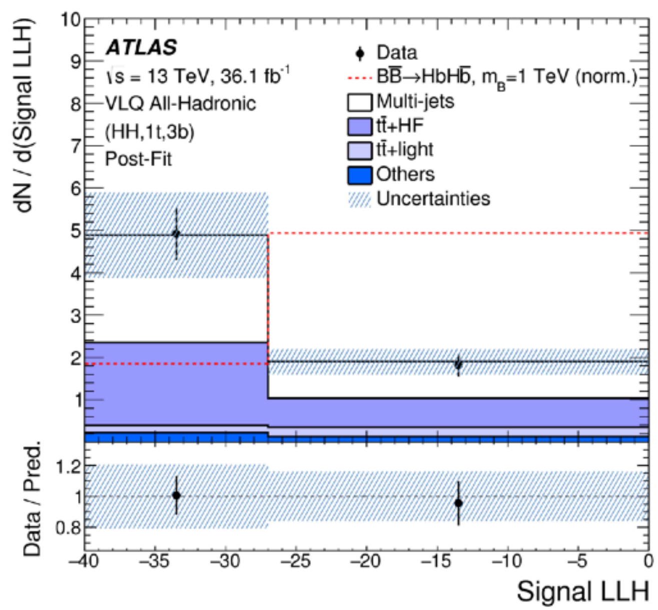
arXiv:1808.01771



- Selects **0-lepton events** with **high-p_T** top quarks or V/H bosons
  - sub-channels depending on boosted object content (12 channels)
- **Main background**: multi-jet (data-driven)
- Boosted object tagging: **multi-class DNN classifier** on vRC jets
  - using of jet and subjet kinematic properties
- Final discriminant: **Matrix Element Method**

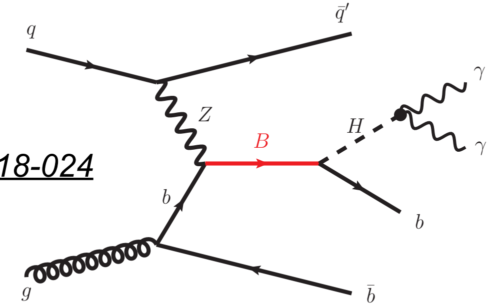
Background suppression





Single-production searches

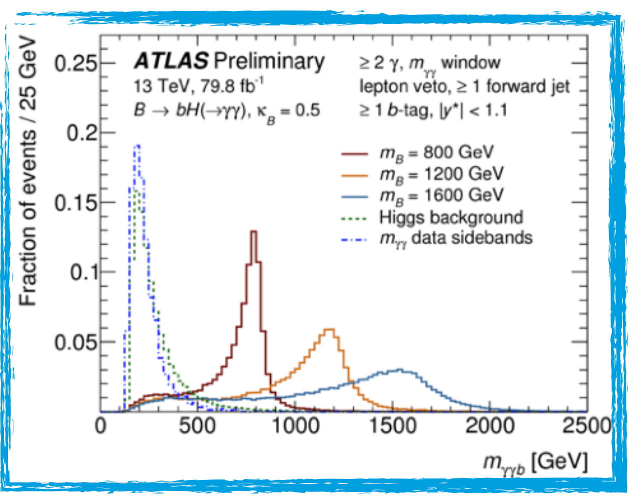
Single $B \to Hb \to \gamma\gamma b$

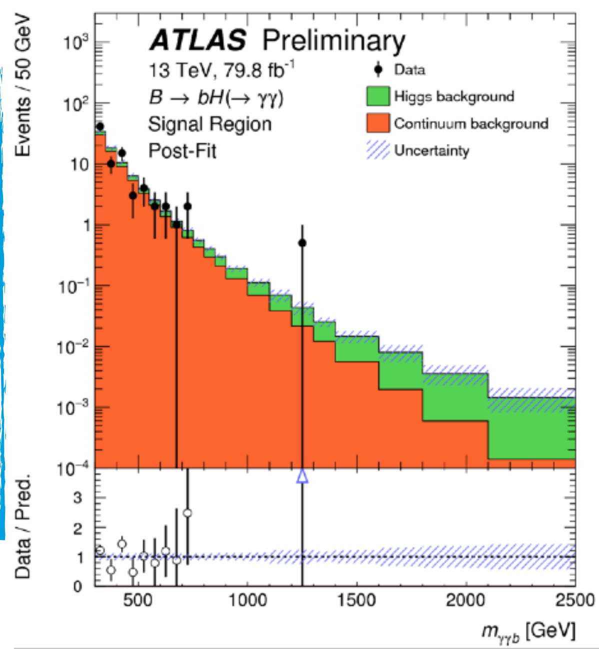


ATLAS-CONF-2018-024

- Selects **events with two photons** originating from Higgs + **b-jet**
  - Use $m_{\gamma\gamma b}$ to **reconstruct vector-like B mass**
- Main background: continuum $\gamma\gamma +$ jets (estimated from data in sidebands)

With 2017 data!

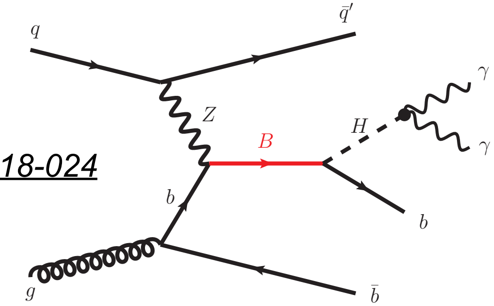




Single-production searches

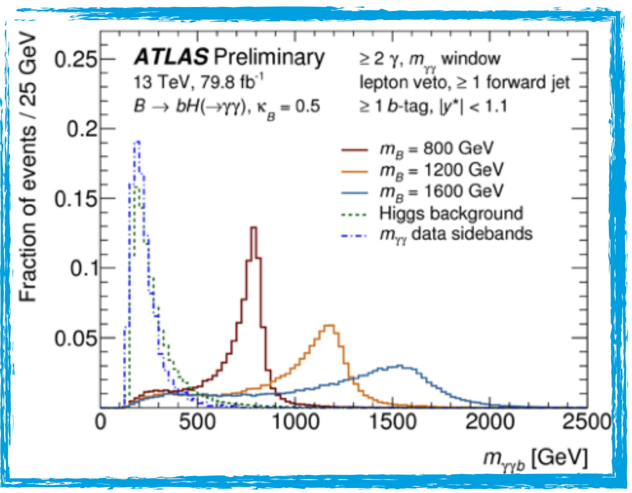
Single $B \to Hb \to \gamma\gamma b$

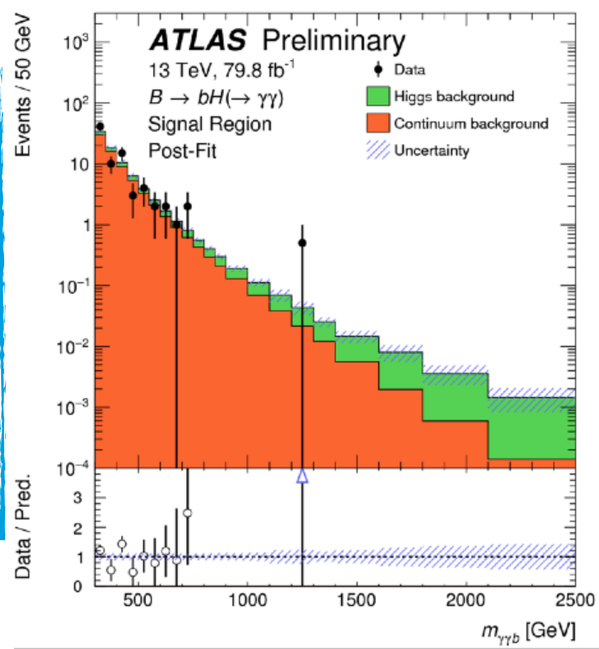
ATLAS-CONF-2018-024

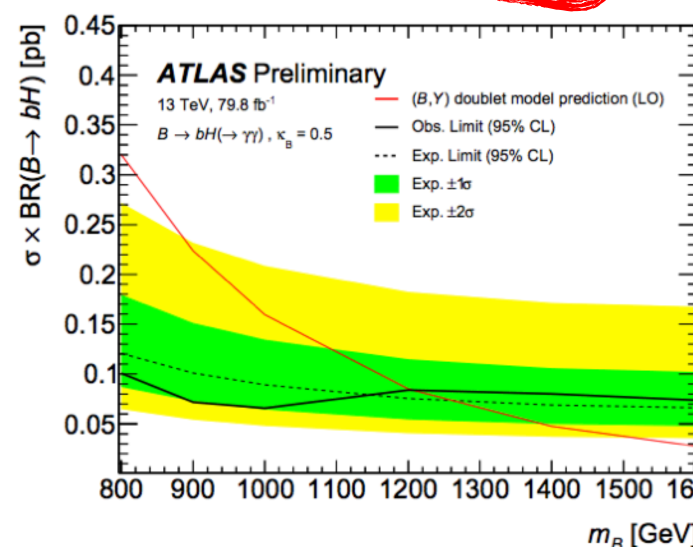


- Selects **events with two photons** originating from Higgs + **b-jet**
  - Use $m_{\gamma\gamma b}$ to **reconstruct vector-like B mass**
- Main background: continuum $\gamma\gamma +$ jets (estimated from data in sidebands)
- Limits set with **fixed coupling**

With 2017 data!



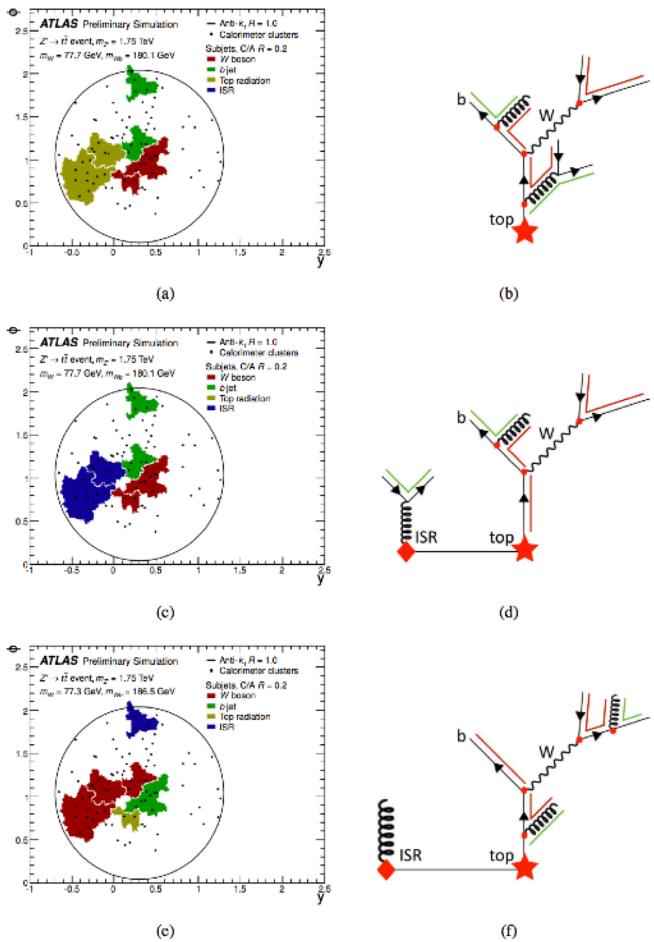




Shower deconstruction algorithm

A bit more information

- Taken from https://cds.cern.ch/record/1648661

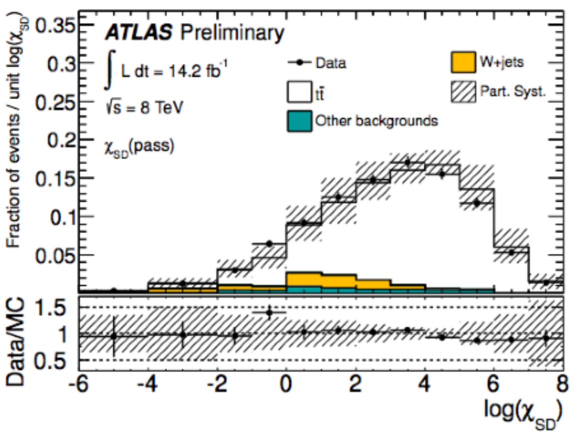


- Subjets used as proxies to parton
- All parton shower history leading to this parton configuration are used: **each has a probability**

sum over signal-hypotheses PS histories

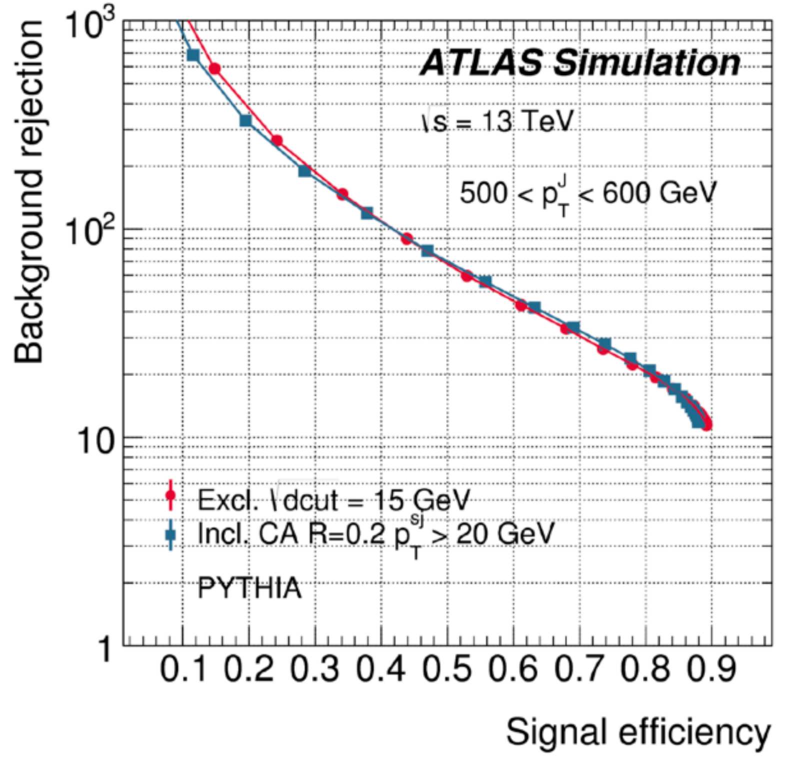
$$\chi_{\mathrm{SD}}(\{p\}_N) = \frac{P(\{p\}_N|\mathrm{S})}{P(\{p\}_N|\mathrm{B})} = \frac{\boxed{\sum_{\text{histories}} P(\{p, c^j\}_N|\mathrm{S})}}{\boxed{\sum_{\text{histories}} P(\{p, c^j\}_N|\mathrm{B})}}$$

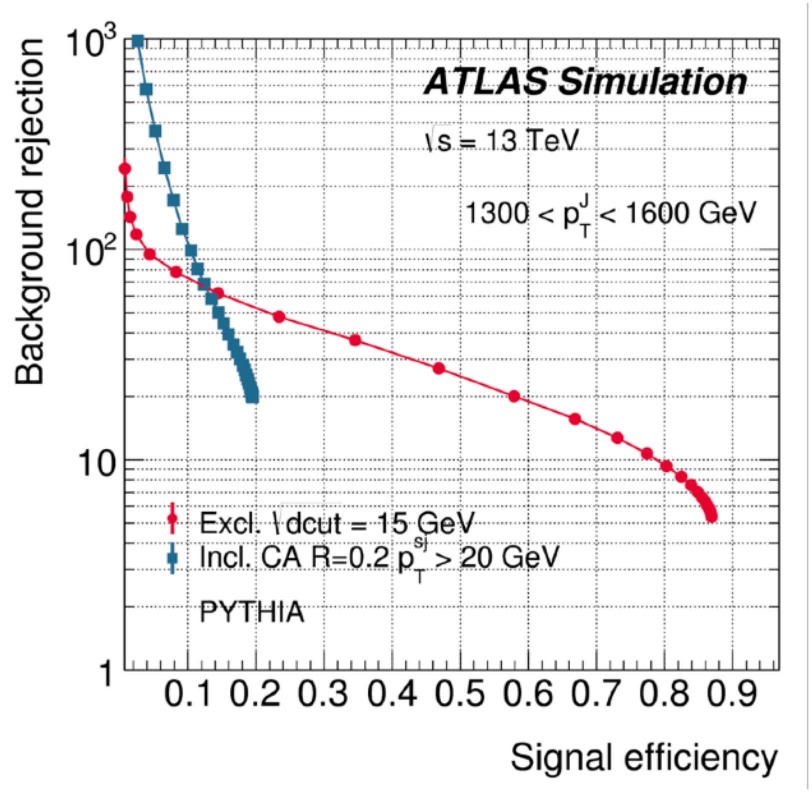
sum over background-hypotheses PS histories



Shower deconstruction performance

A bit more information



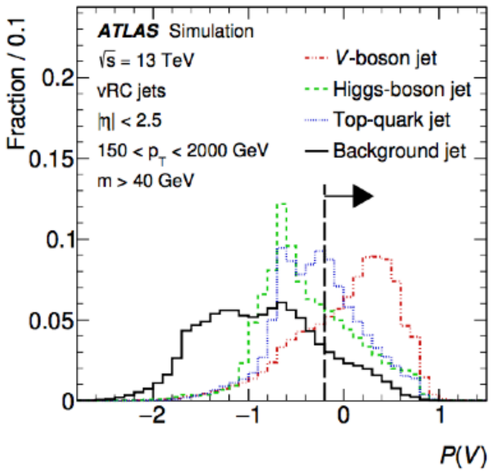


- Use of **exclusive subjets** => better performance for very-highly-boosted top quarks.

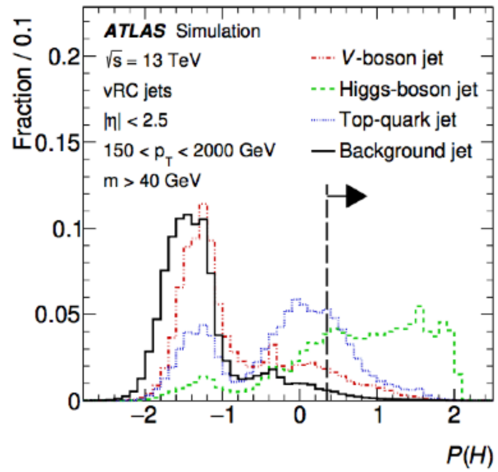
DNN tagger

A bit more information

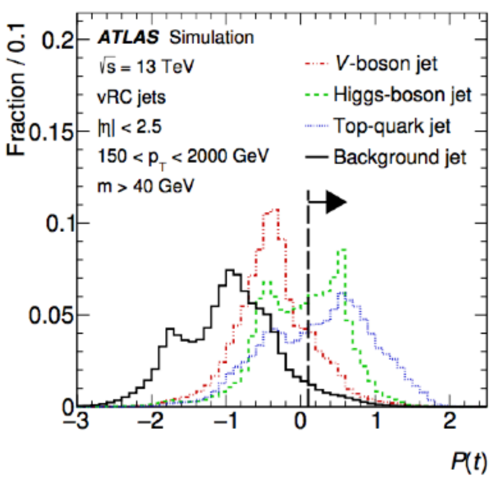
https://arxiv.org/pdf/1808.01771.pdf



(a)



(b)



(c)

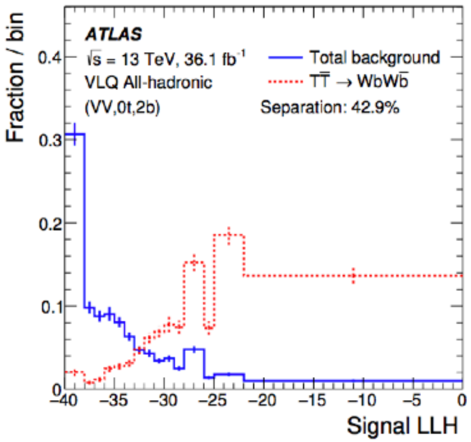
$$P(V) = \log_{10}\left(\frac{D^{V}_{\mathrm{DNN}}}{0.9\cdot D^{\mathrm{background}}_{\mathrm{DNN}} + 0.05\cdot D^{t}_{\mathrm{DNN}} + 0.05\cdot D^{H}_{\mathrm{DNN}}}\right),$$

$$P(H) = \log_{10}\left(\frac{D^{H}_{\mathrm{DNN}}}{0.9\cdot D^{\mathrm{background}}_{\mathrm{DNN}} + 0.05\cdot D^{V}_{\mathrm{DNN}} + 0.05\cdot D^{t}_{\mathrm{DNN}}}\right) \text{ and}$$

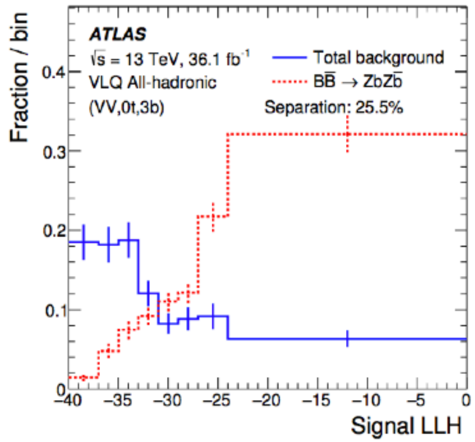
$$P(t) = \log_{10}\left(\frac{D^{t}_{\mathrm{DNN}}}{0.9\cdot D^{\mathrm{background}}_{\mathrm{DNN}} + 0.05\cdot D^{H}_{\mathrm{DNN}} + 0.05\cdot D^{V}_{\mathrm{DNN}}}\right),$$

Matrix element method

A bit more information



(a)



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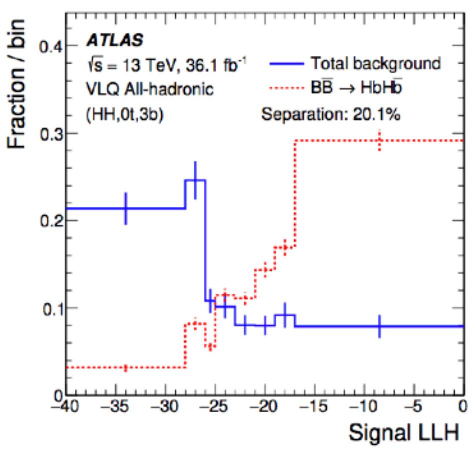

Truth-reco transfer function

Phase space element

$$P_i(\boldsymbol{x}|\boldsymbol{\alpha}) = \frac{(2\pi)^4}{\sigma_i^{\mathrm{eff}}(\boldsymbol{\alpha})} \int d\Phi_N(\boldsymbol{y})\, f(p_A)\, f(p_B)\, \frac{|\mathcal{M}_i(\boldsymbol{y}|\boldsymbol{\alpha})|^2}{\mathcal{F}}\, W(\boldsymbol{y}|\boldsymbol{x})$$

PDF

Transition matrix element of the process

VLQ searches: next steps ?

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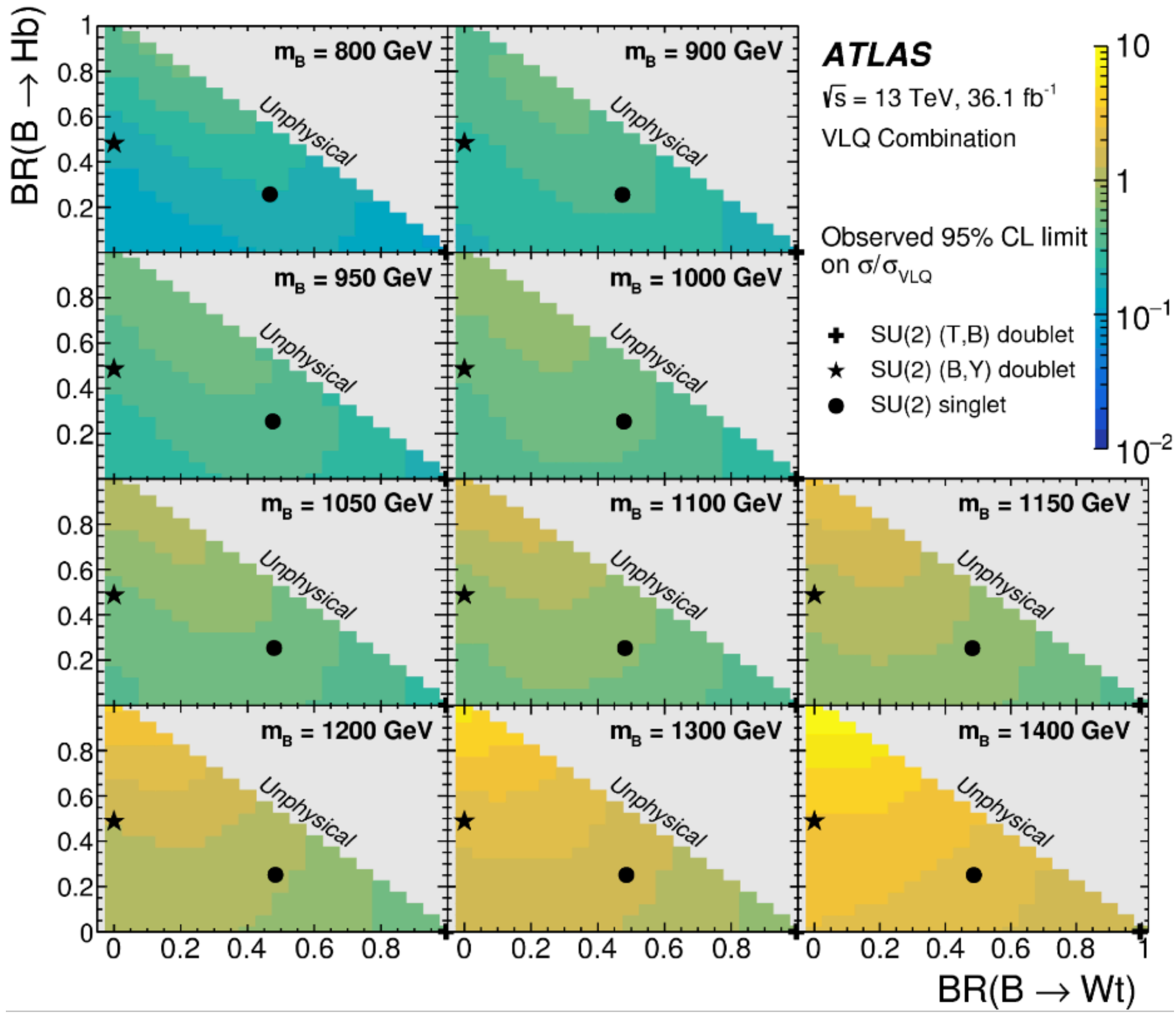
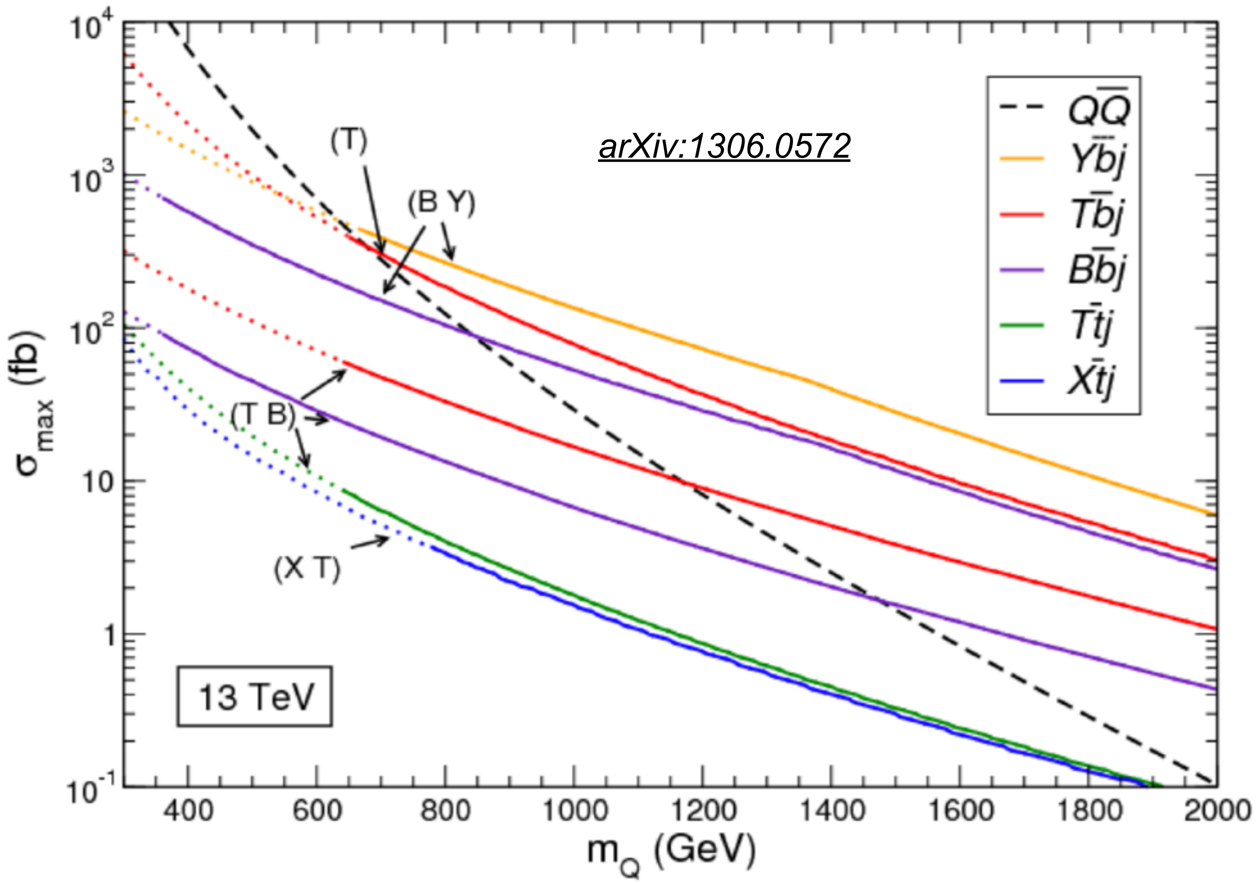


Single VLQ production

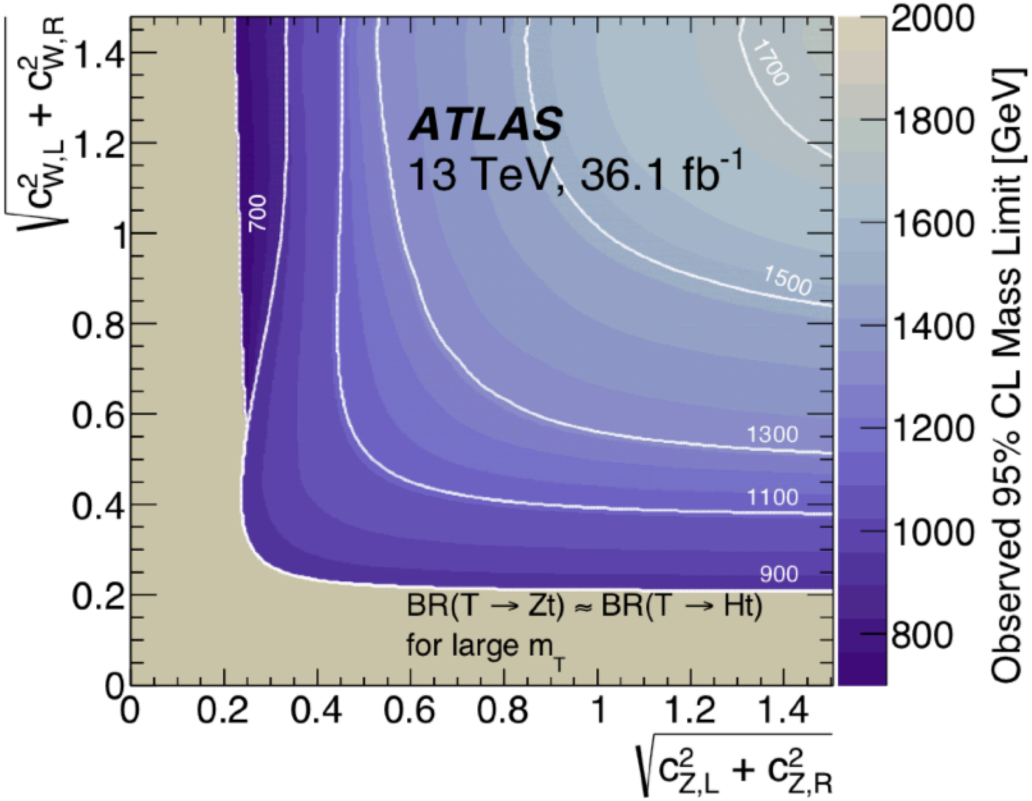
A bit more information

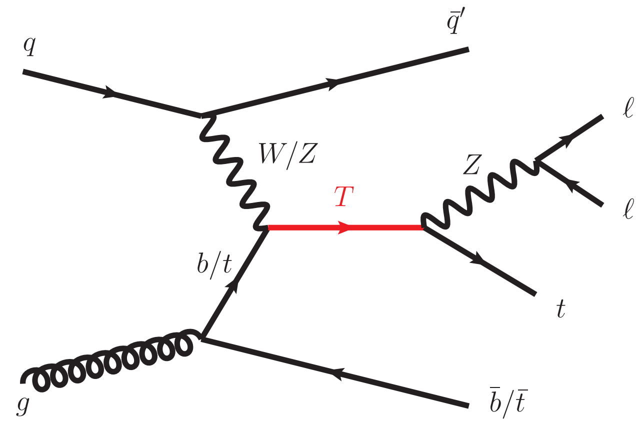
- Single production production cross-section **depends on coupling** between quarks and vector-like partners.



Single VLQ interpretation

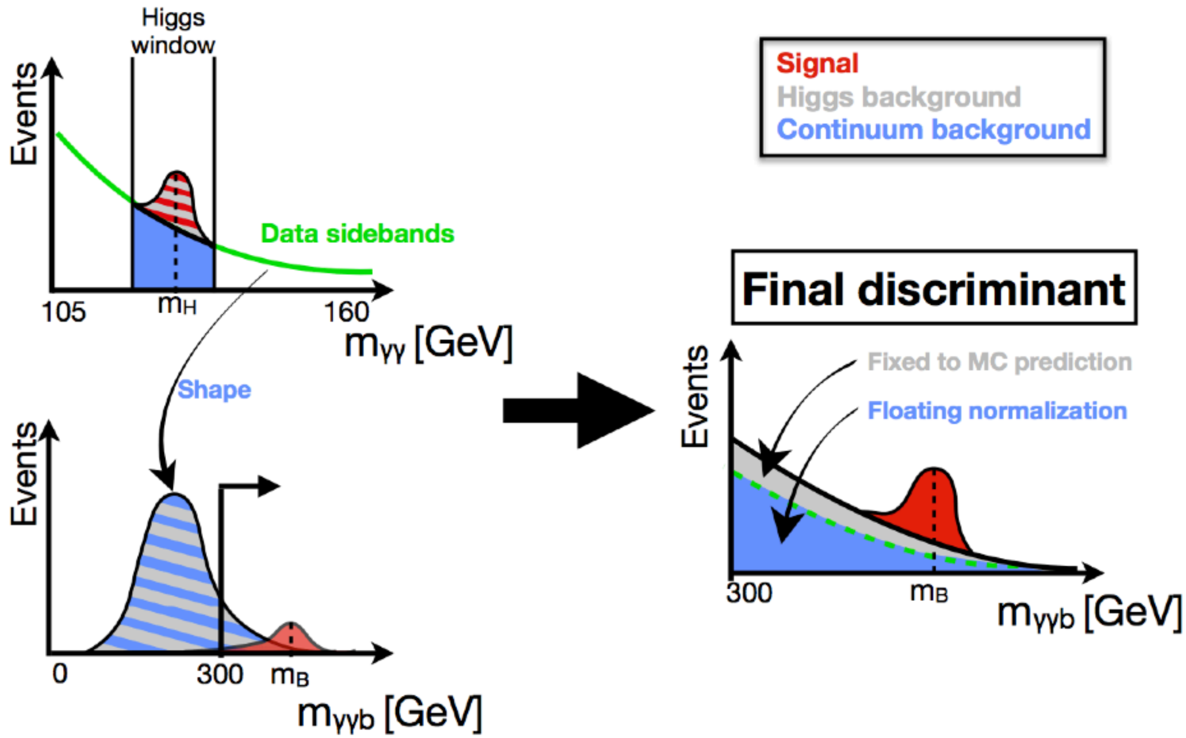
A bit more information





B —> H —> γγb

Some more information

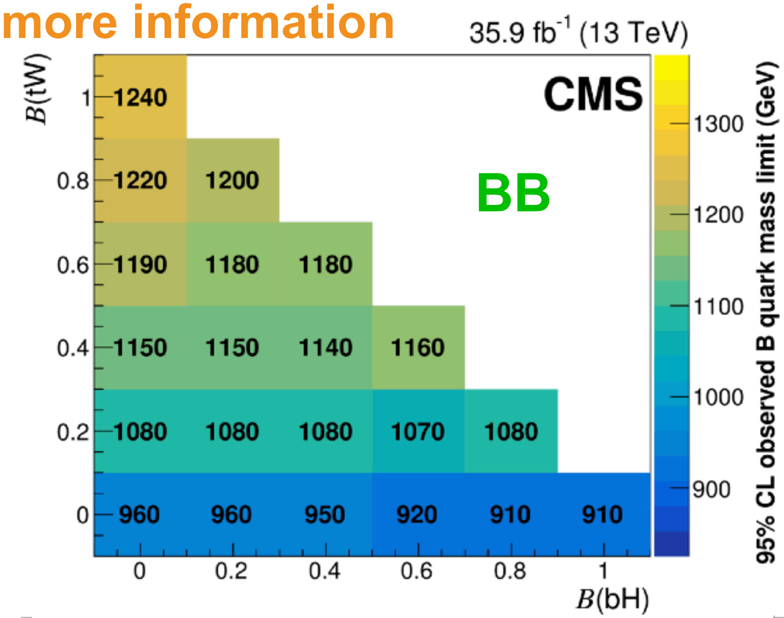


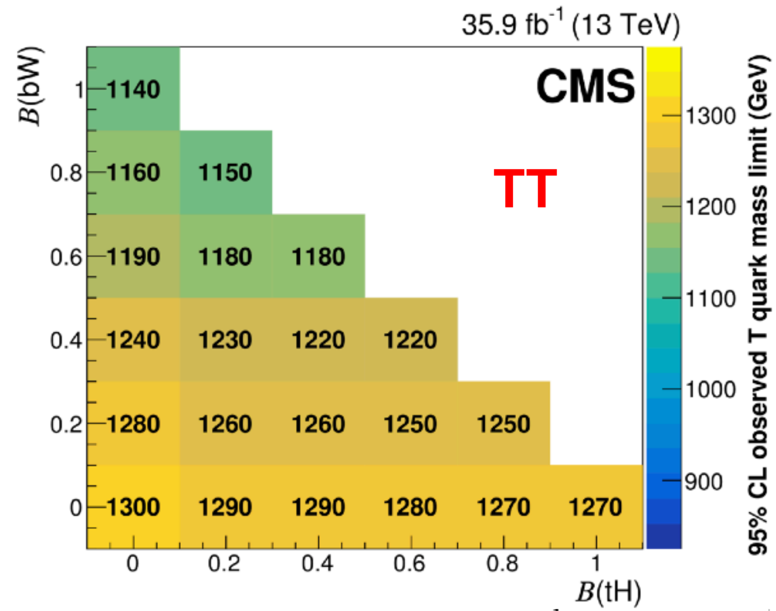
CMS results

arXiv:1805.04758 (Accepted by JHEP)

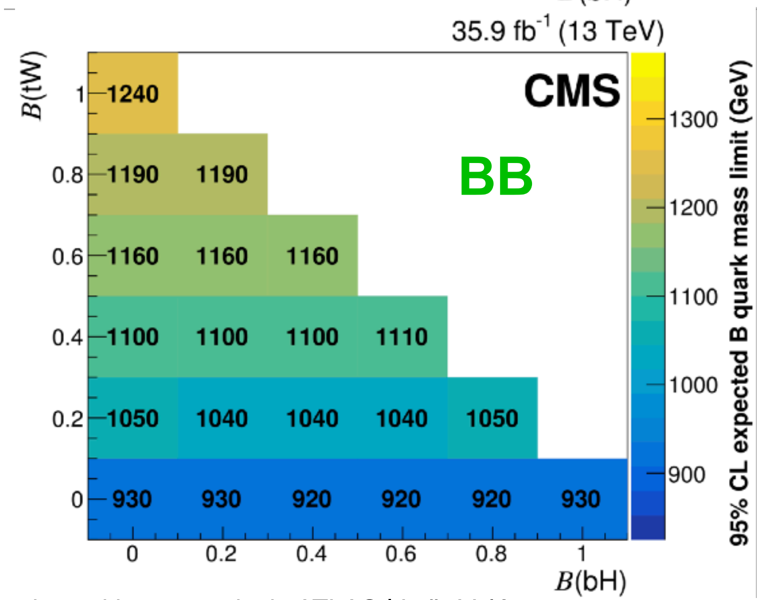
A bit more information

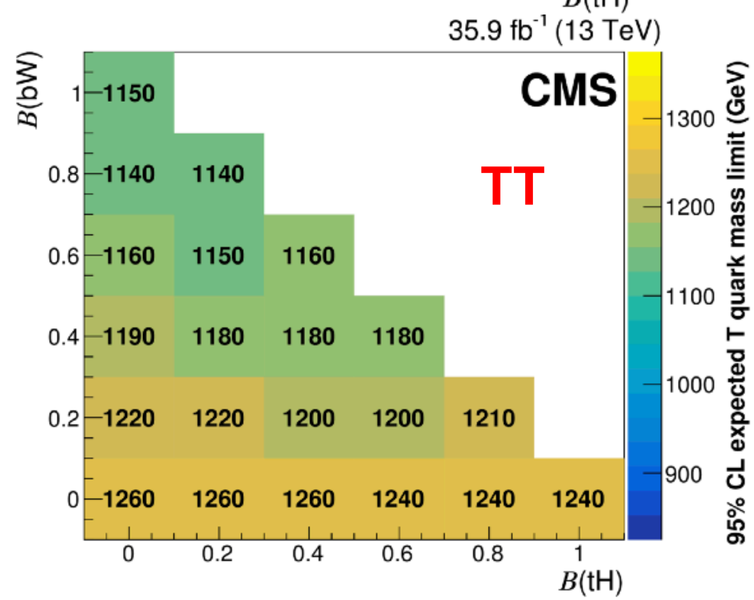
Observed





Expected





ATLAS results

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A bit more information