LABORATÓRIO DE INSTRUMENTAÇÃO
E FÍSICA EXPERIMENTAL DE PARTÍCULAS
partículas e tecnologia

[Search for vector-like quarks]

Tiago Vale
Supervisors: Nuno Castro, Patricia Conde

IDPASC

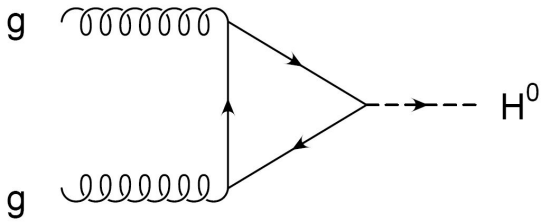
PhD Students Workshop
July 1st, 2019

PD/BD/135435/2017

POCI/01-0145-FEDER-029147 PTDC/FIS-PAR/29147/2017, financiado por fundos OE/FCT, Lisboa2020, Compete2020, Portugal 2020, FEDER

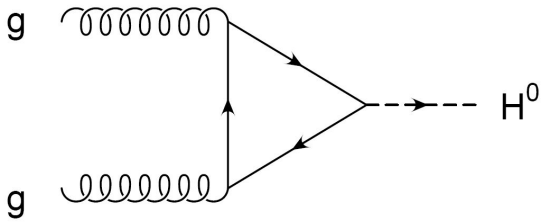
Introduction to vector-like quarks

Motivation for
Vector-like quarks



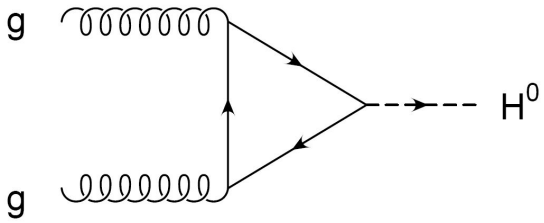
- A new family of quarks must be **vectorial**
  - A new chiral family with ~600 GeV blows up the gg → H cross-section by an order of magnitude

Motivation for
Vector-like quarks



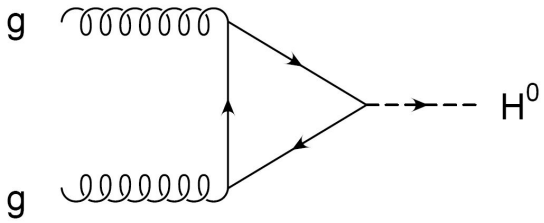
- A new family of quarks must be **vectorial**
  - A new chiral family with ~600 GeV blows up the gg → H cross-section by an order of magnitude
  - VLQ have the **same** **left**- and **right**-handed quantum numbers

Motivation for
Vector-like quarks



- A new family of quarks must be **vectorial**
  - A new chiral family with ~600 GeV blows up the gg → H cross-section by an order of magnitude
  - VLQ have the same left- and right-handed quantum numbers
    - ➢ Dirac mass terms avoids Higgs constraints

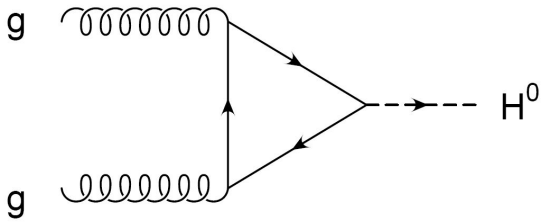
Motivation for
Vector-like quarks



- A new family of quarks must be **vectorial**
  - A new chiral family with ~600 GeV blows up the $gg \rightarrow H$ cross-section by an order of magnitude
  - VLQ have the same left- and right-handed quantum numbers
    - ➢ Dirac mass terms avoids Higgs constraints

- Predicted in many BSM models that tackle the hierarchy problem
  - **Composite Higgs** models as the main example

Motivation for
Vector-like quarks

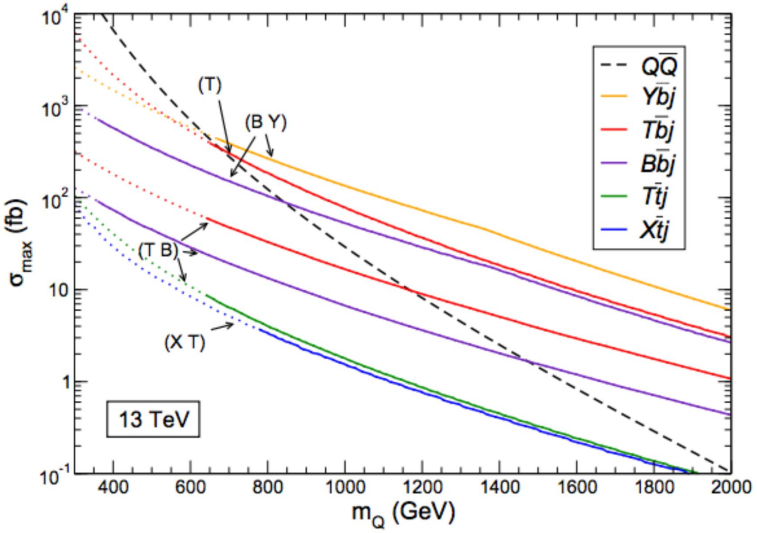


- A new family of quarks must be **vectorial**
  - A new chiral family with ~600 GeV blows up the gg → H cross-section by an order of magnitude
  - VLQ have the same left- and right-handed quantum numbers
    - ➢ Dirac mass terms avoids Higgs constraints

- Predicted in many BSM models that tackle the hierarchy problem
  - **Composite Higgs** models as the main example
    - ➢ See **Maria Ramos** talk on these models

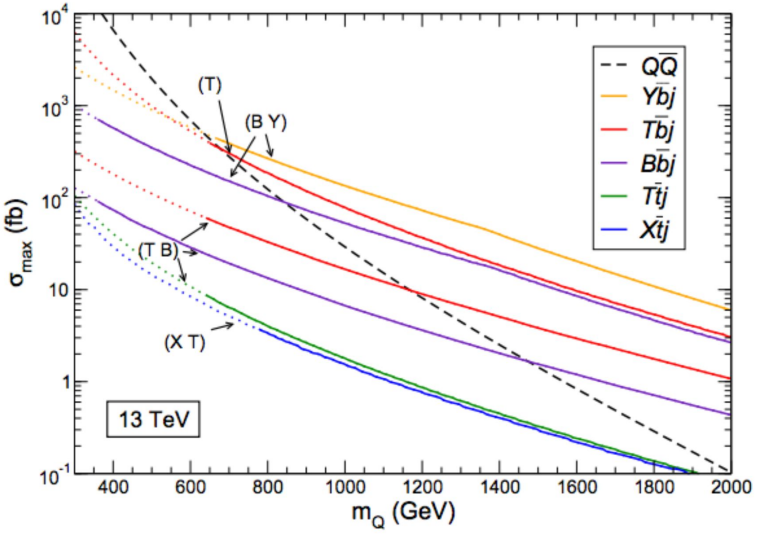
Phenomenology of Vector-like quarks

- VLQs can be **pair**- and **singly**-produced



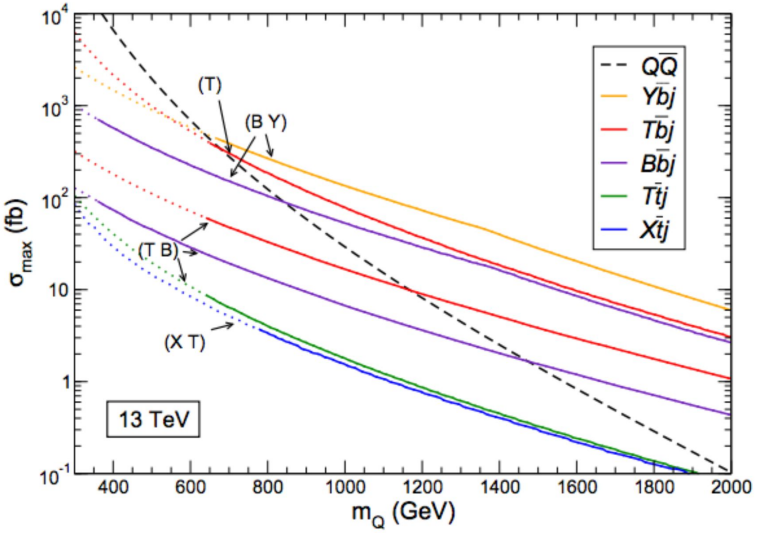
Phenomenology of Vector-like quarks

- VLQs can be **pair**- and **singly**-produced
- SU(2) singlets, doublets or triplets



Phenomenology of Vector-like quarks

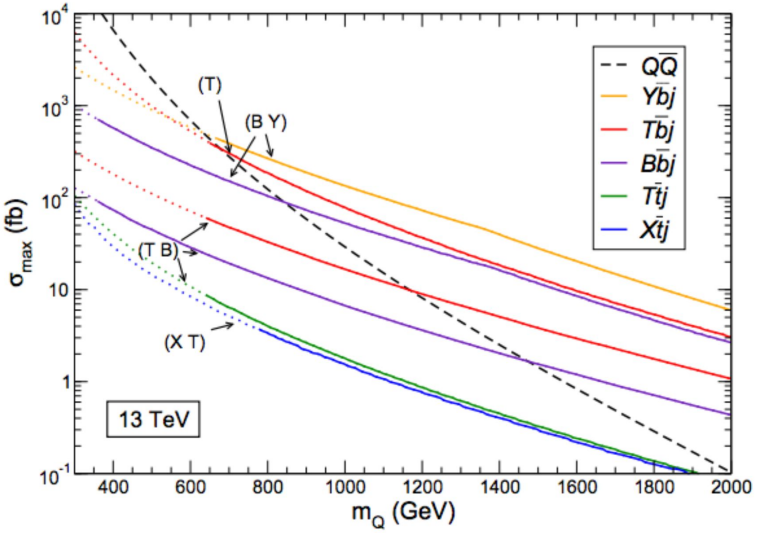
- VLQs can be **pair**- and **singly**-produced
- SU(2) singlets, doublets or triplets
- SM-like electric charges
  - ⅔ (T) or -⅓ (B)
- Exotic electric charges
  - -4/3 (X) or 5/3 (Y)



Phenomenology of Vector-like quarks

- VLQs can be **pair**- and **singly**-produced
- SU(2) singlets, doublets or triplets
- SM-like electric charges
  - ⅔ (T) or -⅓ (B)
- Exotic electric charges
  - -4/3 (X) or 5/3 (Y)

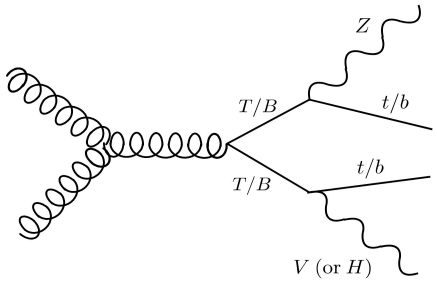
Disregarded in our searches



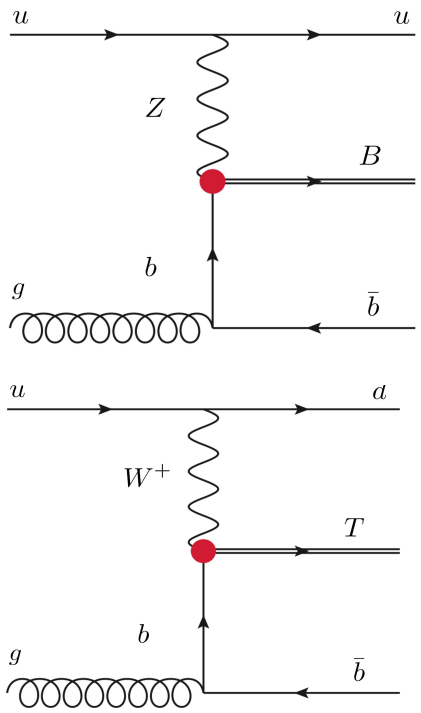
Search for vector-like quarks

10.1103/PhysRevD.98.112010

Partial Dataset

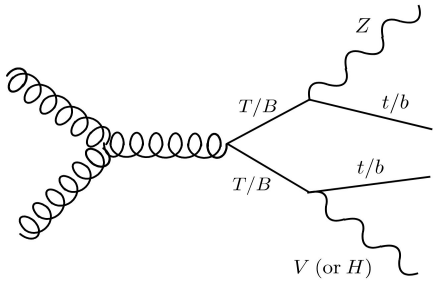


- Search with data from 2015+2016 (36.1/fb)
- Looking for final states with a reconstructed ***Z*** boson
- Some assumptions were made:
  - Only **SM decays** (i.e. W/Z/H + t/b)
  - Pair-production is **SM gluon fusion**
    - These two will be revisited
  - Singlet and doublet kinematic differences are **negligible**
    - Tested throughout the analysis development

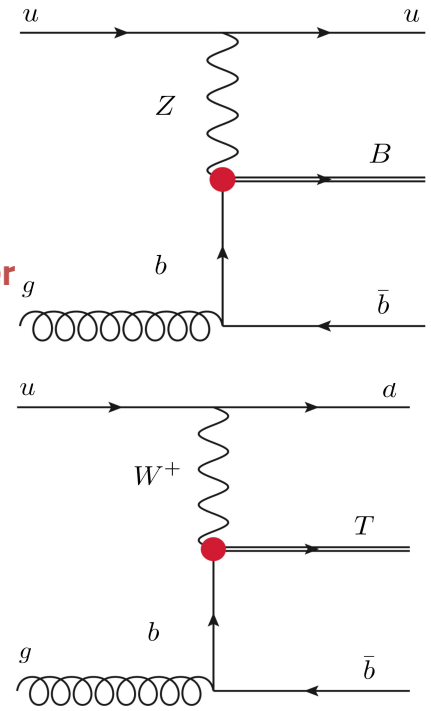


10.1103/PhysRevD.98.112010

Partial Dataset

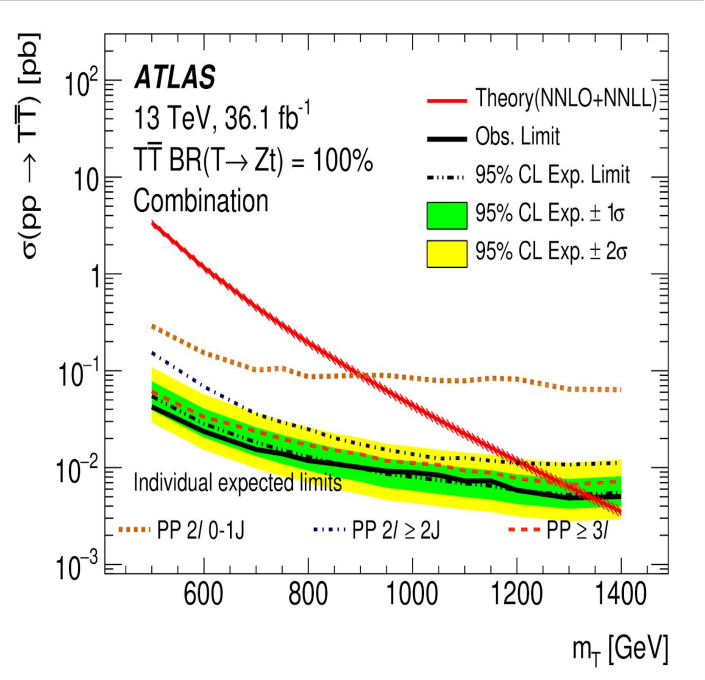


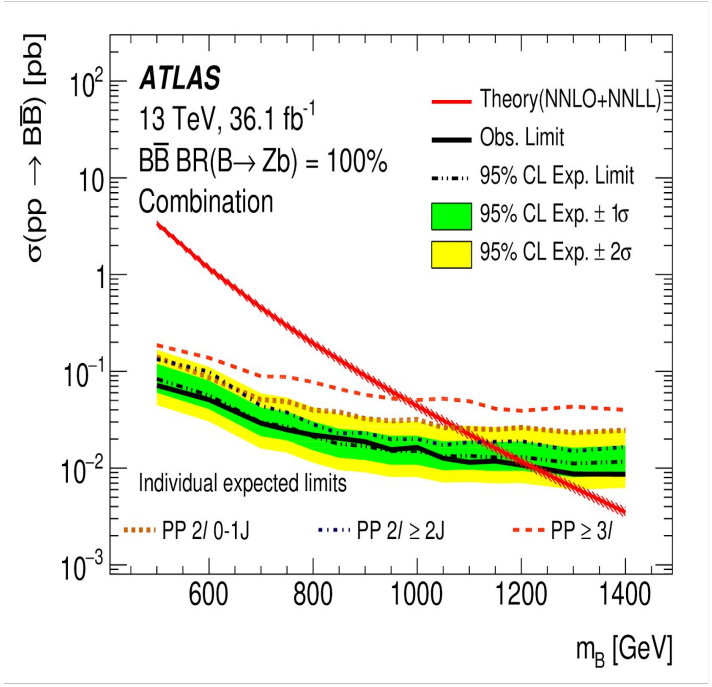
- Search with data from 2015+2016 (36.1/fb)
- Looking for final states with a reconstructed ***Z*** boson
- Some assumptions were made:
  - Only **SM decays** (i.e. W/Z/H + t/b) **More about this later**
  - Pair-production is **SM gluon fusion**
    - These two will be revisited
  - Singlet and doublet kinematic differences are **negligible**
    - Tested throughout the analysis development



10.1103/PhysRevD.98.112010

Partial
Dataset





- Reached 1.2 - 1.3 TeV limits
- **Statistics** as the most limiting factor
  - New data from 2017 and 2018 should boost results

10.1103/PhysRevLett.121.211801

Combination of searches

- Having analysis dedicated to a final state allows to fully explore each topology
- ATLAS strategy covers most VLQ decays to SM

10.1103/PhysRevLett.121.211801

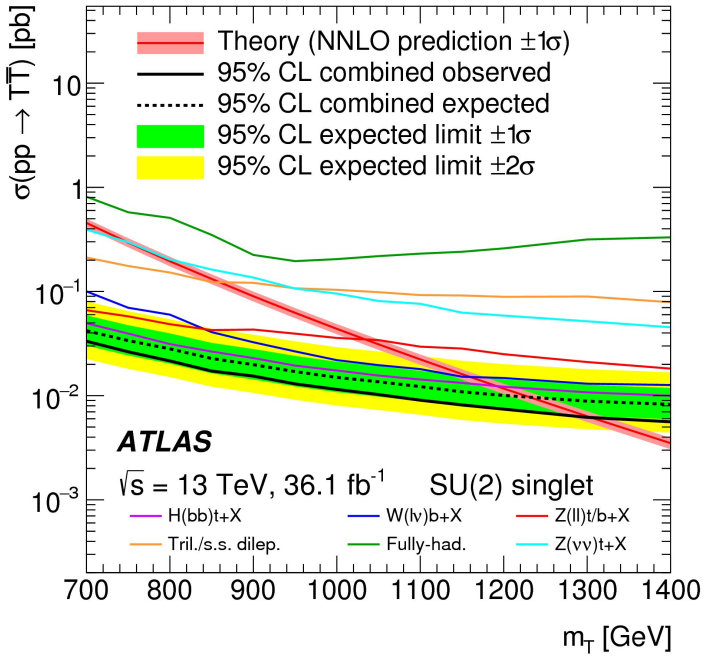
Combination of searches

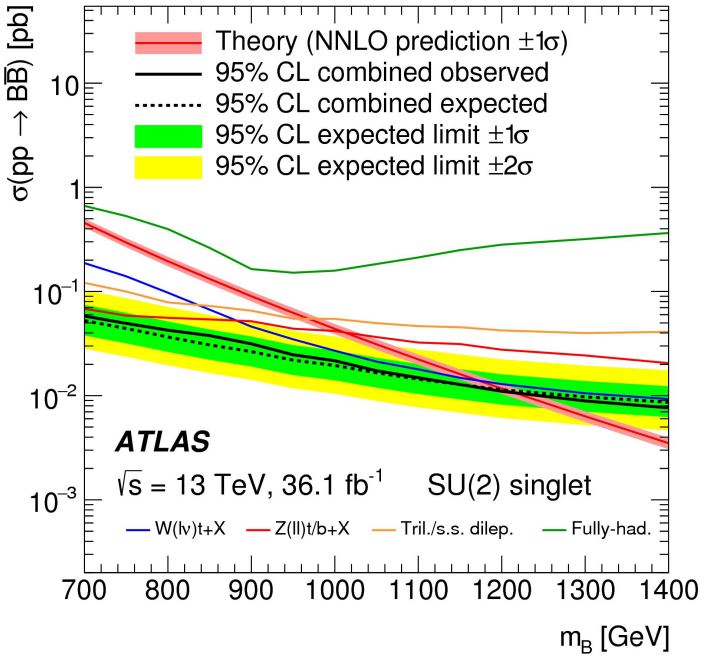
- Having analysis dedicated to a final state allows to fully explore each topology
- ATLAS strategy covers most VLQ decays to SM
- An ATLAS wide combination should bring the best of both worlds
  - Final state specific optimization for each analysis
  - Statistical improvement from combining all analyzed events

10.1103/PhysRevLett.121.211801

Combination of searches

- An ATLAS wide combination should bring the best of both worlds
  - Final state specific optimization for each analysis
  - Statistical improvement from combining all analyzed events



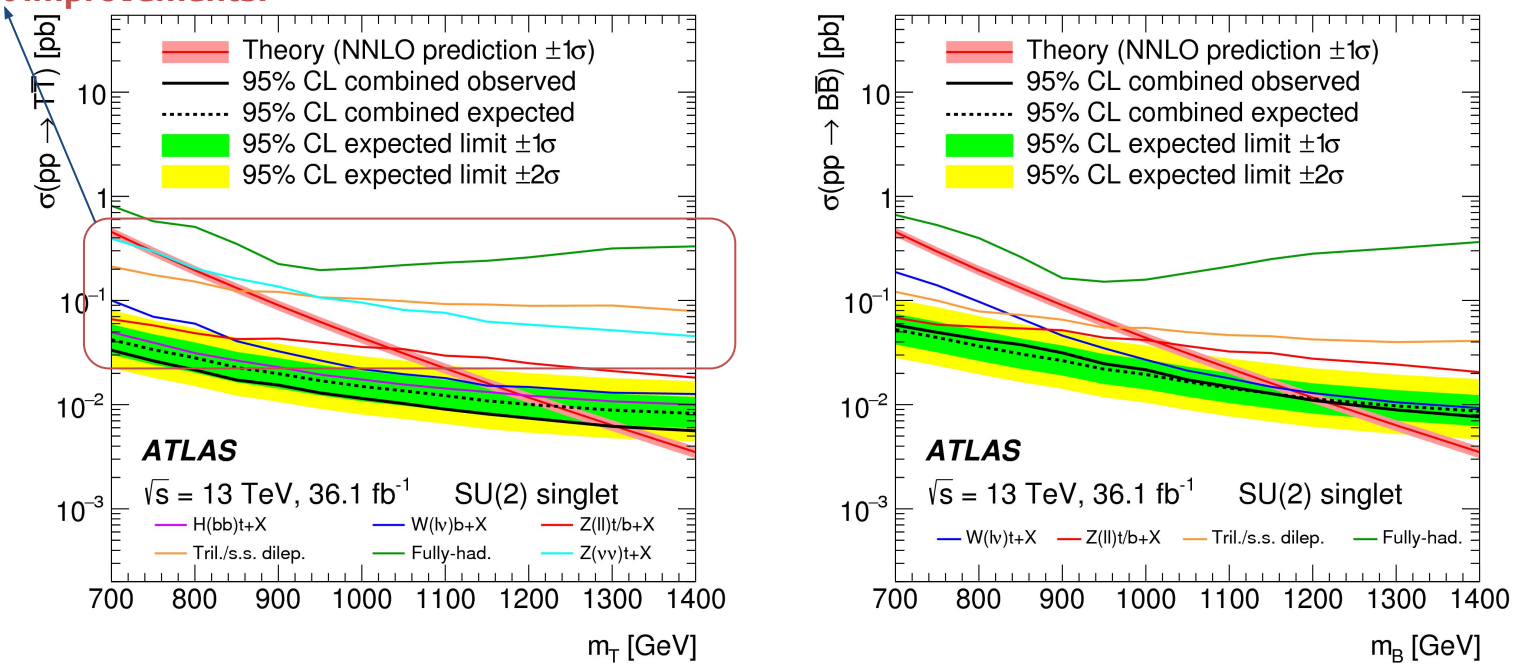


10.1103/PhysRevLett.121.211801

Combination of searches

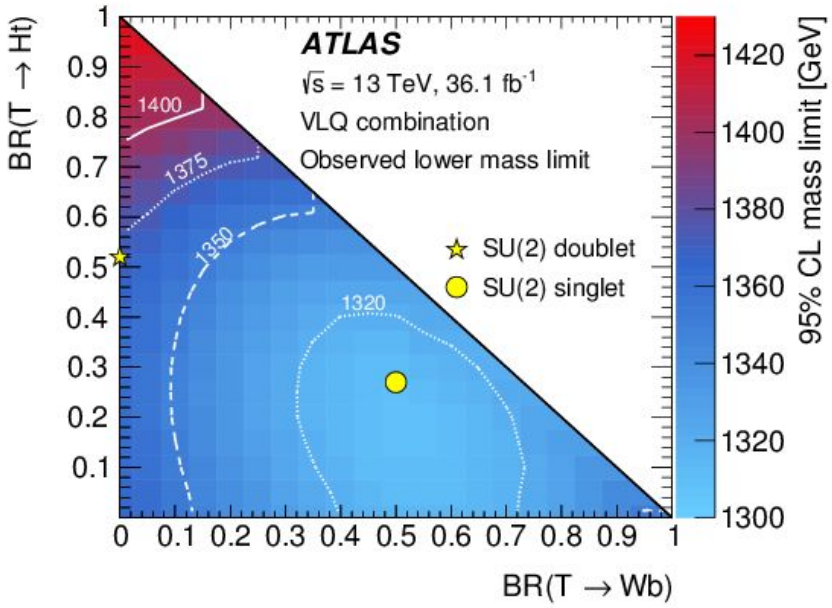
- An ATLAS wide combination should bring the best of both worlds
  - Final state specific optimization for each analysis
  - Statistical improvement from combining all analyzed events

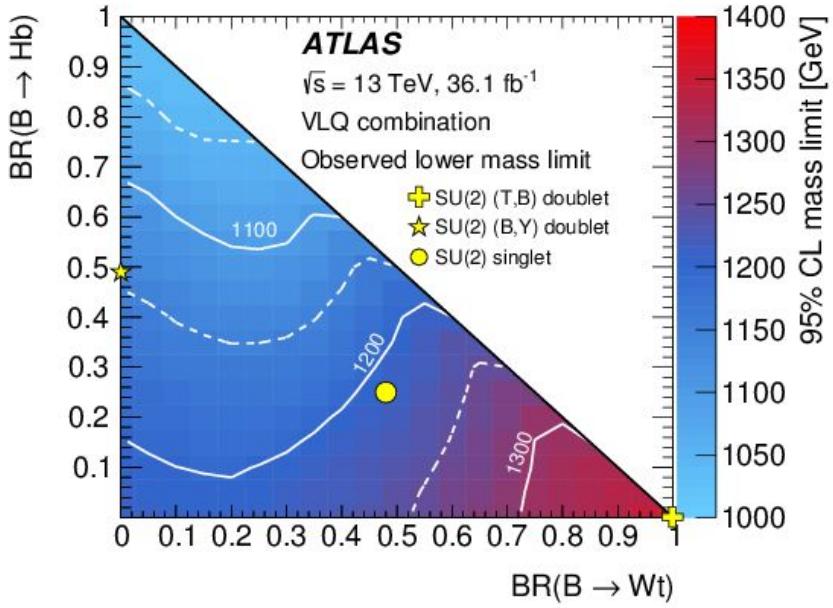
Significant improvements!



10.1103/PhysRevLett.121.211801

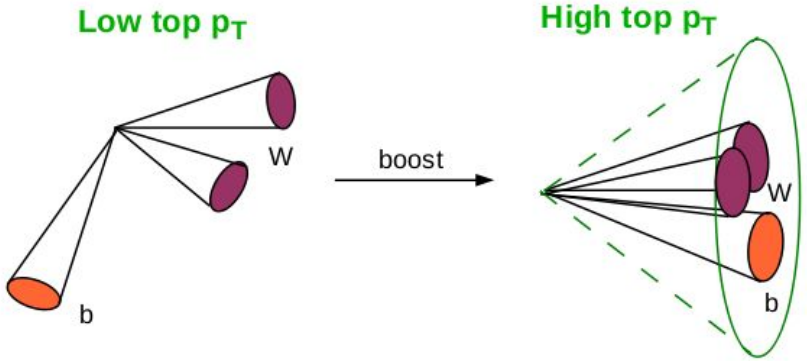
Combination of searches





- Combining all ATLAS pair-production searches provides sensitivity across the branching ratio plane

Full Run 2
Dataset



- Update the search using the full run-2 dataset
  - 140/fb (factor ~4 improvement)

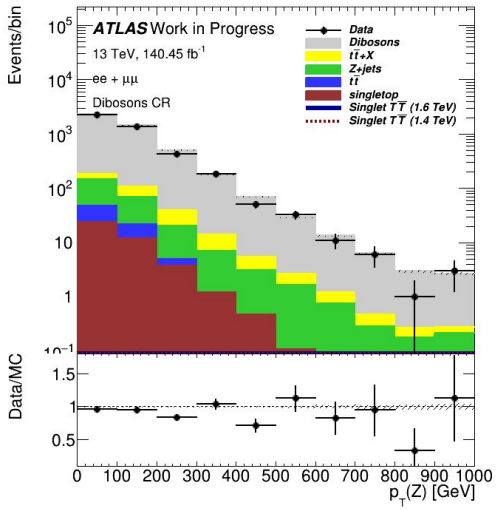
- Can we fully benefit from more statistics?
  - New channel splitting
  - Regions reoptimization based on novel items
    - Neural network to tag large-R jets
      - V/H/top tagging

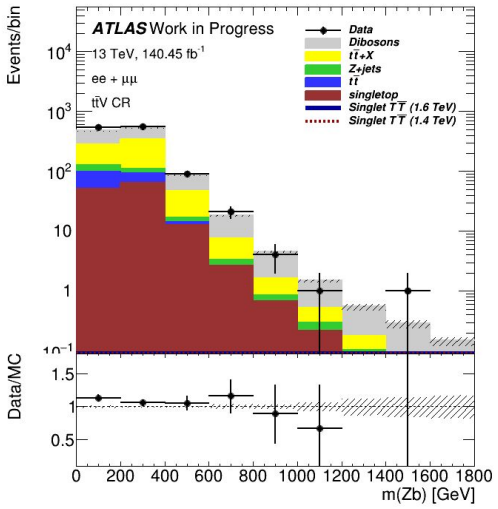
- Experience and machinery from the last iteration will speed things up

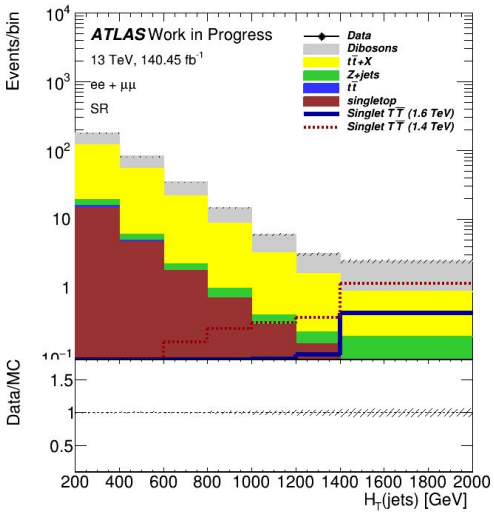
Full Run 2
Dataset

- Ongoing analysis
  - Good modelling of major backgrounds
  - Signal region is still blinded
  - Increase in statistics will allow try new ideas

- Planning a publication by early next year



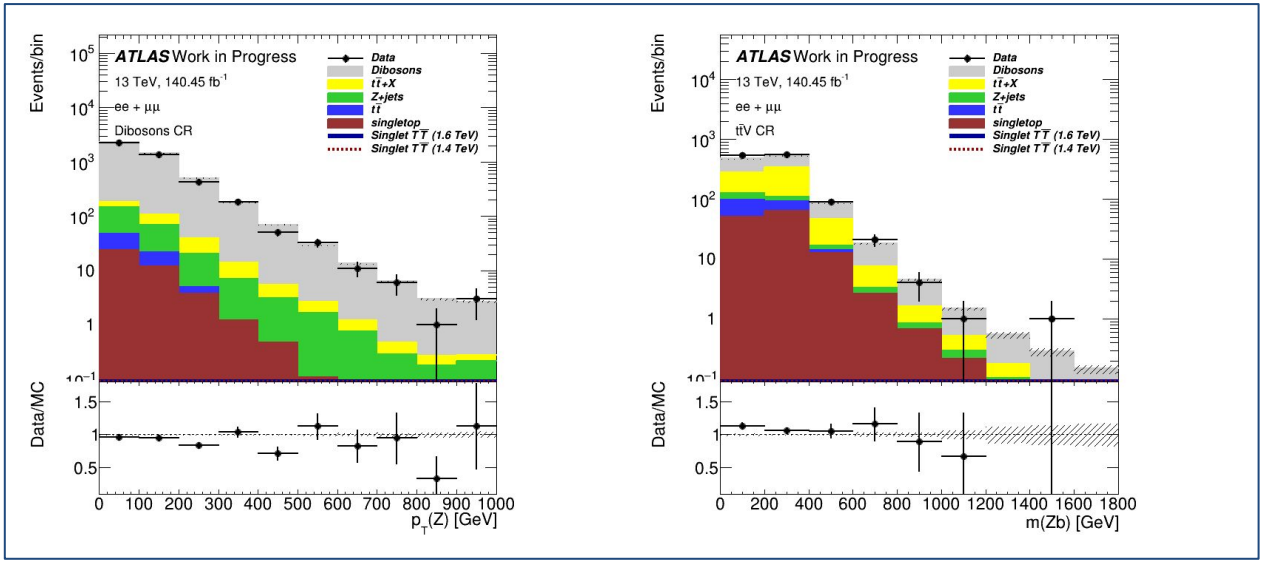




Full Run 2
Dataset

- Ongoing analysis
  - Good modelling of major backgrounds
  - Signal region is still blinded
  - Increase in statistics will allow try new ideas

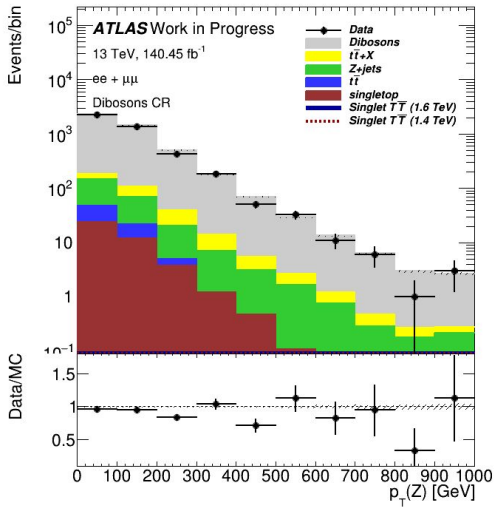
- Planning a publication by early next year

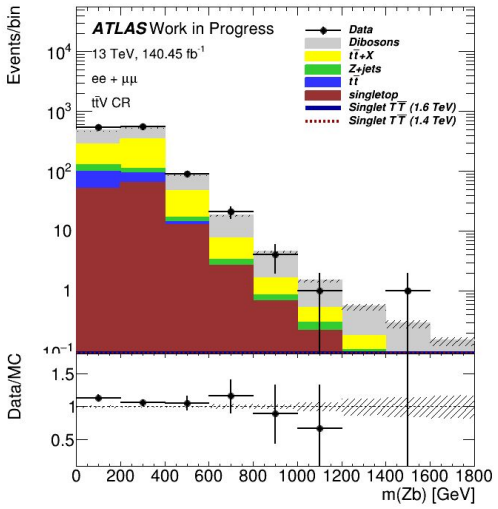


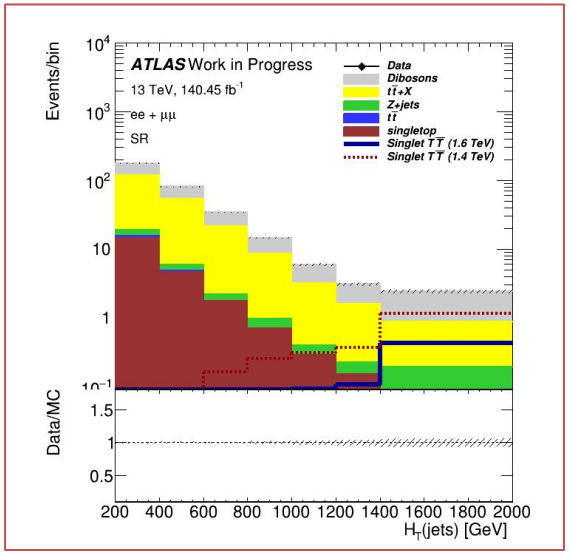
Full Run 2
Dataset

- Ongoing analysis
  - Good modelling of major backgrounds
  - Signal region is still blinded
  - Increase in statistics will allow try new ideas

- Planning a publication by early next year



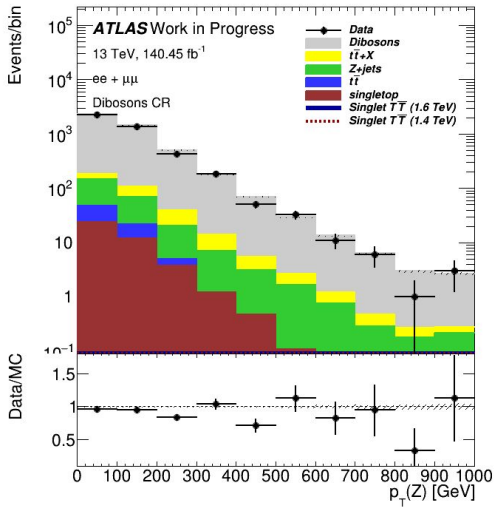


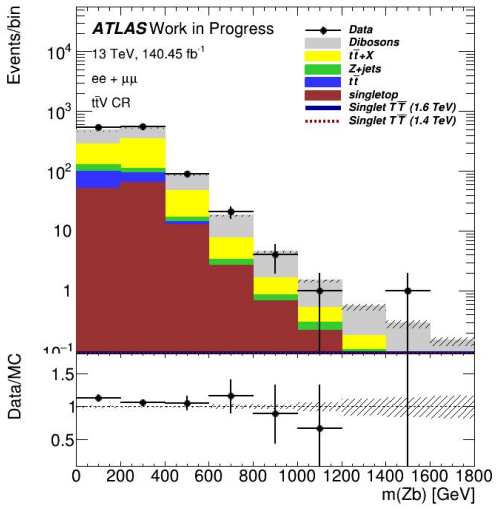


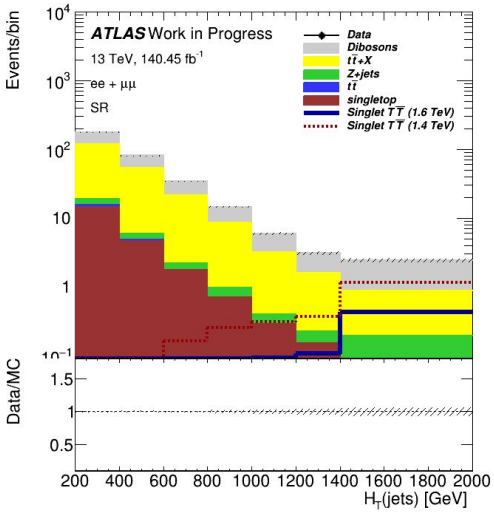
Full Run 2
Dataset

- Ongoing analysis
  - Good modelling of major backgrounds
  - Signal region is still blinded
  - Increase in statistics will allow try new ideas

- Planning a publication by **early next year**







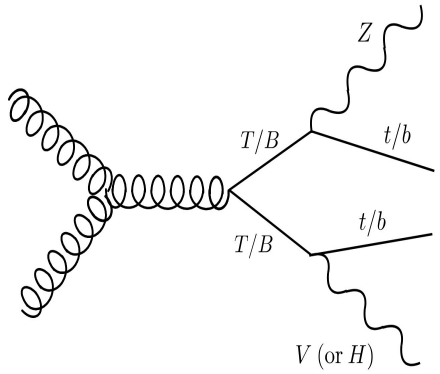
Heavy gluons

Heavy gluon interpretation

- **Composite Higgs** models that predict VLQ as top partners also predict **heavy gluons** as the composite counterpart to the SM gluon
  - EW fits put their lower mass limit at ~ **3 TeV**
  - They can mix with VLQ

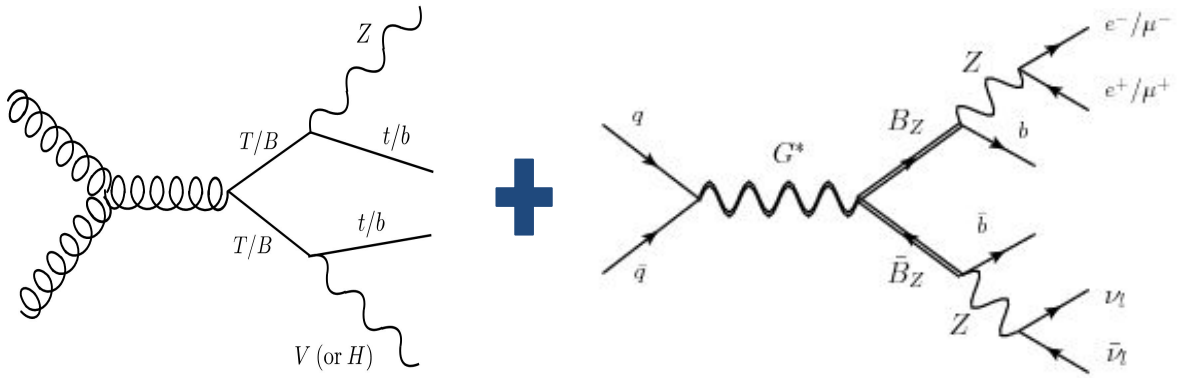
Heavy gluon interpretation

- **Composite Higgs** models that predict VLQ as top partners also predict **heavy gluons** as the composite counterpart to the SM gluon
  - EW fits put their lower mass limit at ~ **3 TeV**
  - **They can mix with VLQ**



Heavy gluon interpretation

- **Composite Higgs** models that predict VLQ as top partners also predict **heavy gluons** as the composite counterpart to the SM gluon
  - EW fits put their lower mass limit at ~ **3 TeV**
  - **They can mix with VLQ**



Heavy gluon interpretation

- **Composite Higgs** models that predict VLQ as top partners also predict **heavy gluons** as the composite counterpart to the SM gluon
  - EW fits put their lower mass limit at ~ **3 TeV**
  - **They can mix with VLQ**

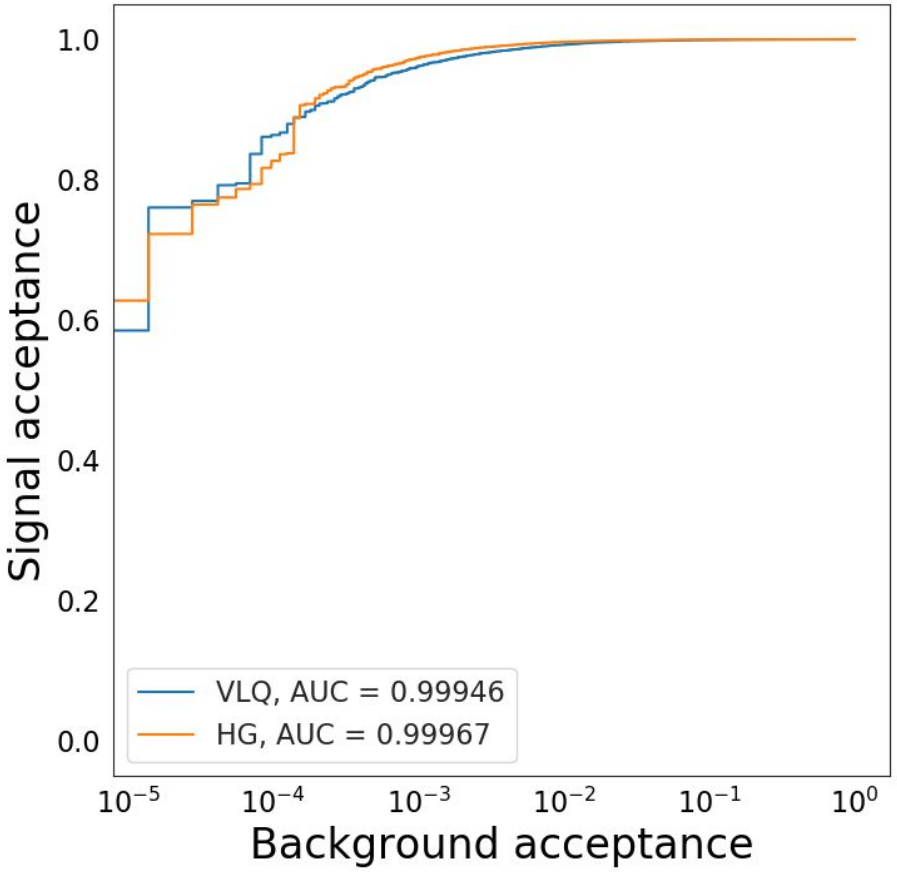
- Can we be missing a signal simply because we made too tight assumptions?
  - Build a neural network to distinguish the two signals
  - Reinterpret the results

Signals vs Backgrounds

- Composite Higgs model

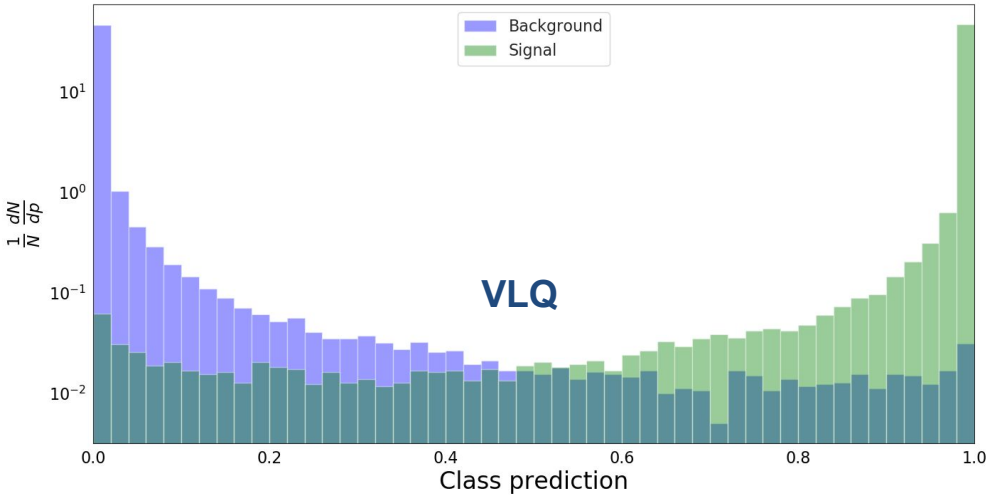
- **Signal** processes:
  - gg -> TT
  - gg -> G -> TT
- **Backgrounds**:
  - ttbar
  - Z + bb
  - Z + cc

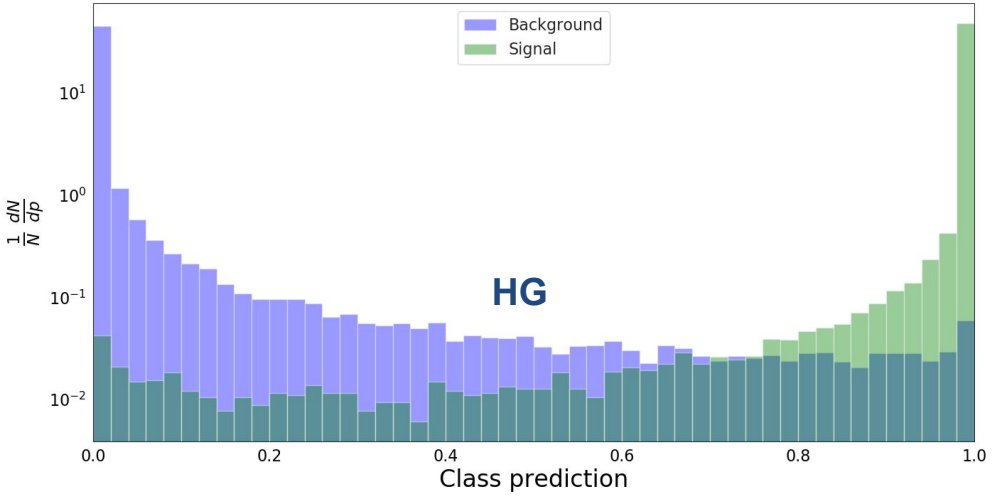
- Heavy gluon (HG) mass of 3 TeV
- VLT of 1 TeV
  - Just starting points



Signals vs Backgrounds

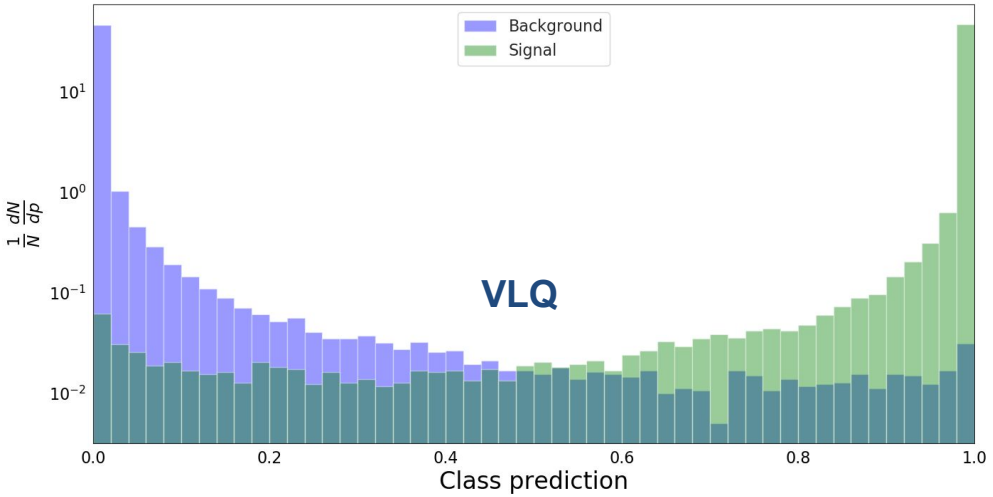
- Good discrimination
- Should be an excellent fitting variable

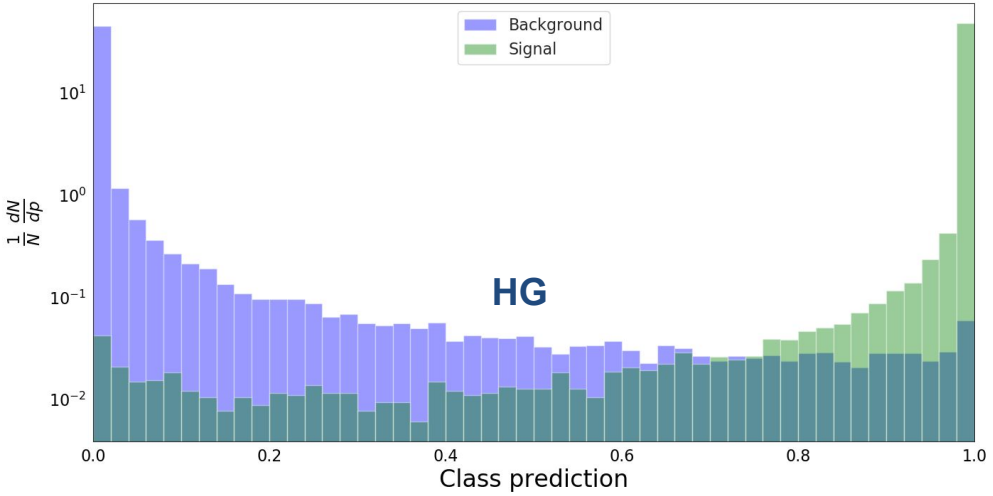




Signals vs Backgrounds

- Good discrimination
- Should be an excellent fitting variable
- **Still be seen if it leads to big effects in the mass limits**





Final Remarks

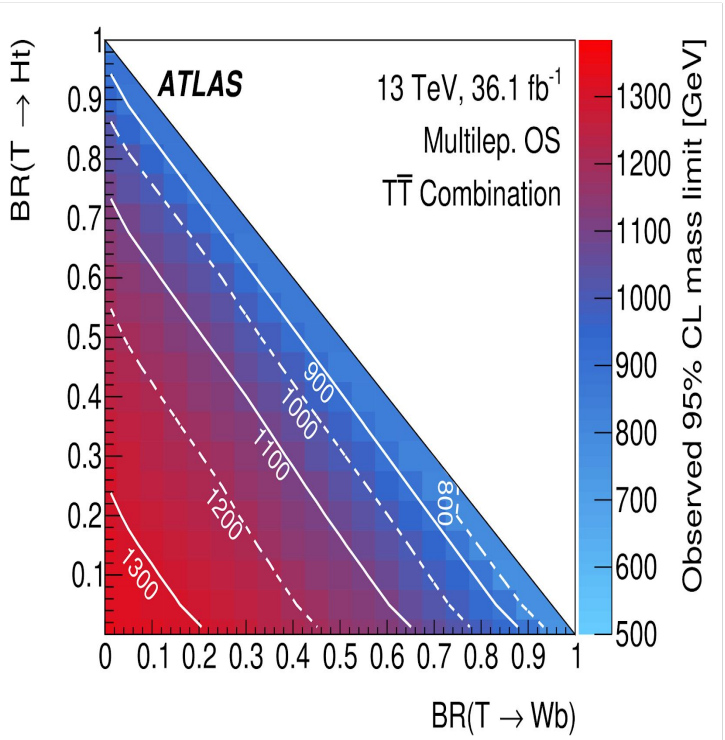
- Analysis with partial dataset (2015+2016 data) was published
  - https://journals.aps.org/prd/abstract/10.1103/PhysRevD.98.112010
- Combination of all ATLAS VLQ analysis with partial dataset was published
  - https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.121.211801
  - PRL editor's choice
- Analysis with full run-2 dataset is ongoing and targeting an early 2020 publication
- Pheno work with heavy gluons reaching the final steps
- PhD to be concluded by early 2021

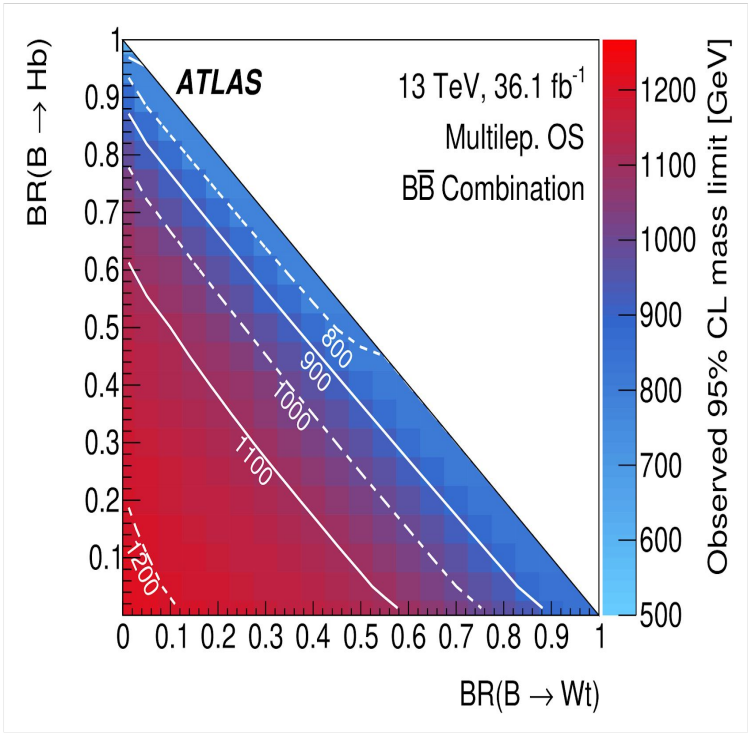
Thanks

tiago.vale@cern.ch

10.1103/PhysRevD.98.112010

Pair-production limits





Model	Dilepton (0–1 large-R jets)	Dilepton ($\geq$ 2 large-R jets)	Trilepton	Combination
$T\bar{T}$ singlet	740 (720) GeV	950 (930) GeV	950 (1010) GeV	1030 (1060) GeV
$T\bar{T}$ doublet	850 (820) GeV	1100 (1100) GeV	1090 (1150) GeV	1210 (1210) GeV
100% $T \rightarrow Zt$	920 (900) GeV	1210 (1210) GeV	1260 (1290) GeV	1340 (1320) GeV
$B\bar{B}$ singlet	860 (840) GeV	930 (950) GeV	890 (940) GeV	1010 (1030) GeV
$B\bar{B}$ doublet	1040 (1000) GeV	1060 (1070) GeV	820 (880) GeV	1140 (1120) GeV
100% $B \rightarrow Zb$	1110 (1080) GeV	1120 (1130) GeV	930 (980) GeV	1220 (1180) GeV