Search for single-production of a vector-like B quark decaying into a bottom quark and a Higgs in the H->bb decay mode with the ATLAS experiment

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SUMMARY

- Introduction
  - Theoretical Motivation
  - VLQ Theoretical Features
  - State of the art in ATLAS
- Analysis Features
  - Analysis Strategy
  - Event Selection
- Background Modelling
  - Strategy
  - Validation and Systematics
- Outlook & Next Steps

MOTIVATION

- **What is a Vector-Like Quark (VLQ)?**

> *"[…]* ***HYPOTHETICAL*** *spin 1/2 particles that transform as triplets under the colour gauge group and whose* ***left and right-handed components have the same colour and EW quantum numbers.*** *"*

Aguilar-Saavedra et al., **arXiv:1306.0572v3**

- **Why does it matter?**
  - **Predicted in models tackling the Hierarchy Problem**
    - **eg. Composite Higgs, Little Higgs**
  - **Does not conflict with the measured Higgs production cross section**
  - **Introduce a new source of CP Violation**

All the aforementioned arguments point to VLQ Mass ~ TeV scale

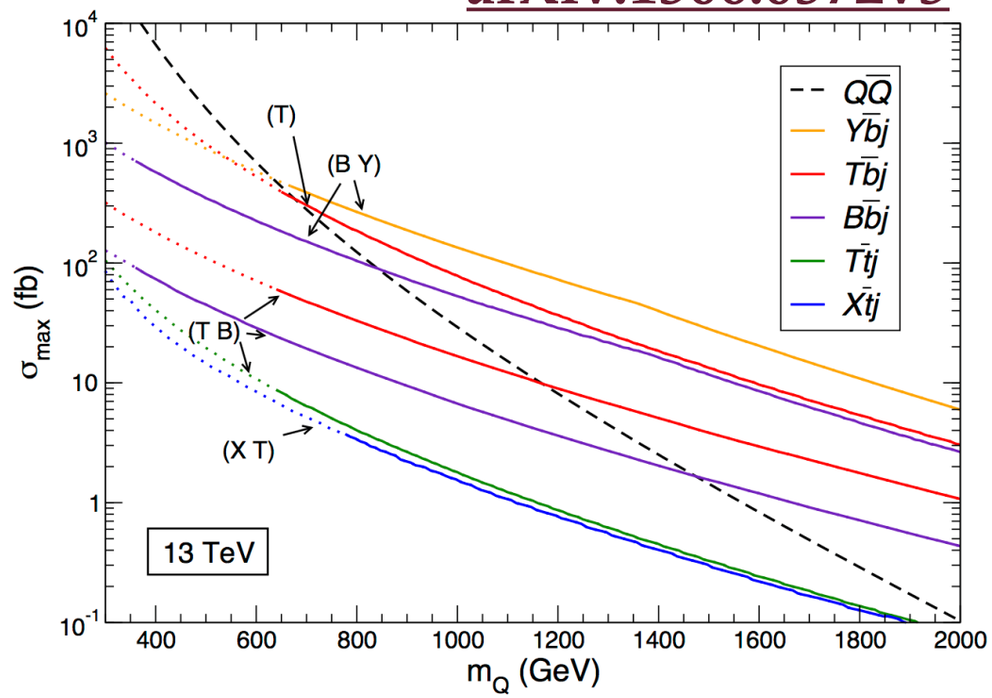
THEORY OVERVIEW

- VLQs can occur as either singlets, doublets or triplets
- Mix prevalently with 3rd generation SM quarks

PRODUCTION

- Two production modes: single / pair production
- Single production dominates at high mass

arXiv:1306.0572v3



DECAY

- Decay modes involve 3rd gen. quarks and gauge/Higgs bosons

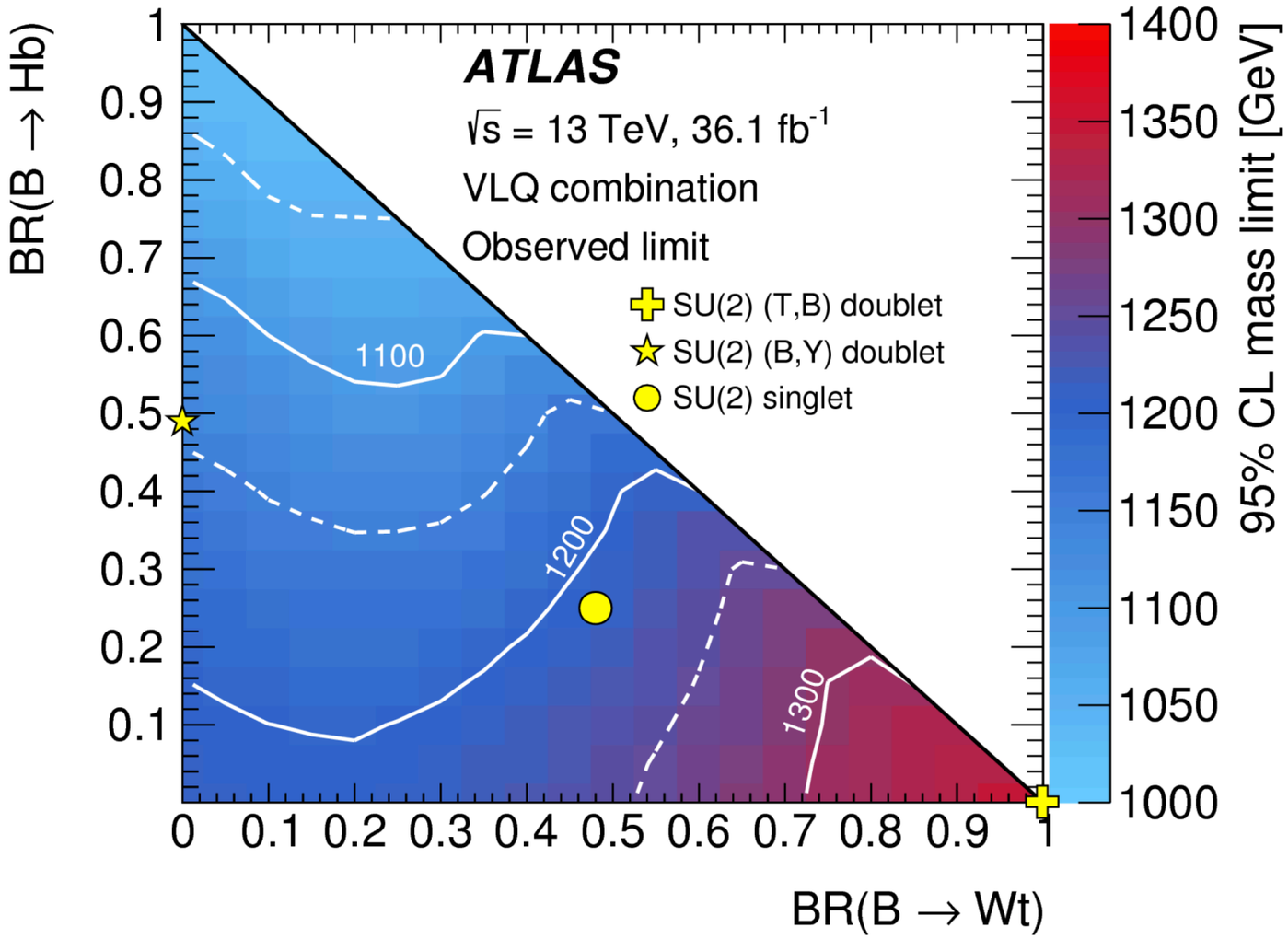
$$\mathrm{Br}(Q \to Wq') + \mathrm{Br}(Q \to Zq) + \mathrm{Br}(Q \to Hq) = 1\,,$$

- Branching ratios differ between singlet/doublet hypotheses:

- **Singlet**
  - $BR(B \to bH) \sim 25\%$
- **(B,Y) doublet**
  - $BR(B \to bH) \sim 50\%$
- **(T,B) doublet**
  - $BR(B \to bH) \sim 0\%$

STATE OF THE ART for VLB

- Several searches currently active on late/full Run 2 data
- Current limits from pair production combination (arXiv:1808.02343)



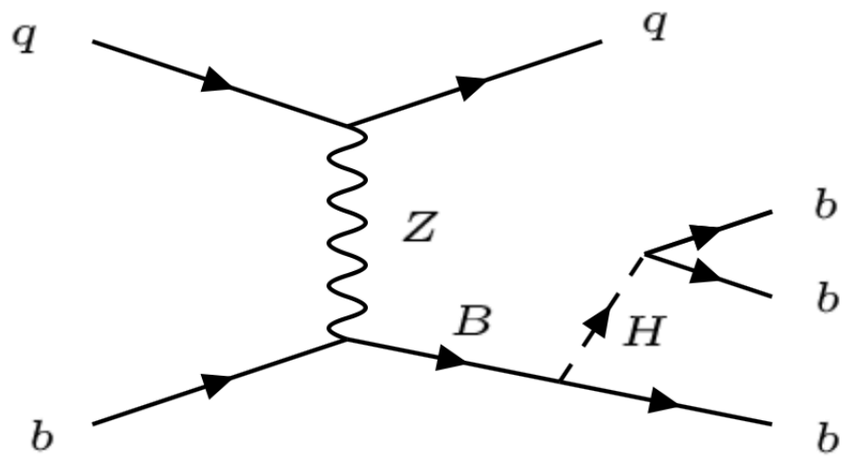
TAKE AWAY!

- **Limits on mass:**

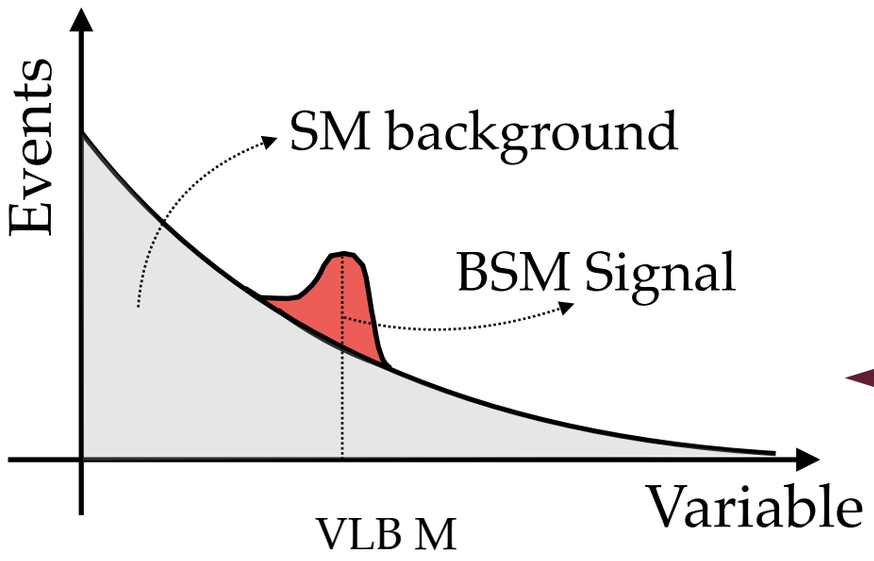
$$M_B > 1200\text{GeV} \quad (doublet)$$
$$M_B > 1150\text{GeV} \quad (B, Y\, singlet)$$

ANALYSIS FEATURES

- **Search for single-production VLB, decay channel** $B \to bH(b\bar{b})$
- **Analysis on full Run 2 data (~140 fb^{-1})**



- **Standard counting experiment strategy**



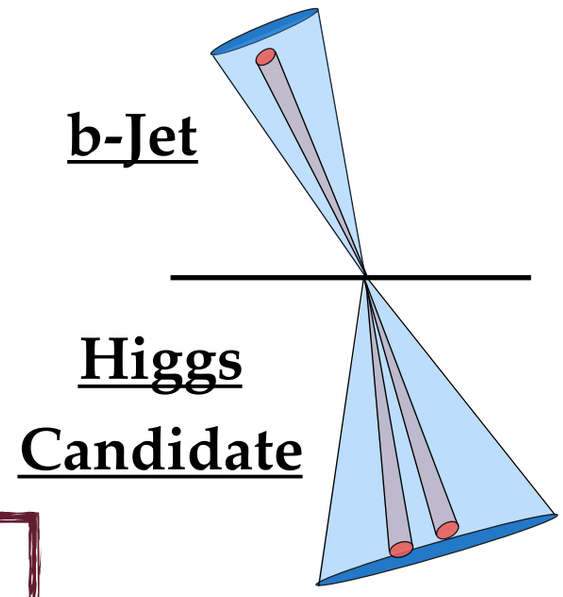
- **<u>Cut based</u> event selection to boost sensitivity**
- **Understand background in Control Regions**

- **Unblind Signal Region data**
- **Study distributions of <u>sensitive variables wrt signal</u>**
- **Evaluate agreement with SM in Signal Region or hunt bumps!**

EVENT RECONSTRUCTION

- **Most sensitive variable: mass of reconstructed VLB decay system**

- **VLB candidate defined as:**
  - **Higgs Candidate: 1 large-R jet (R=1.0)**
  - **b from direct VLB decay: 1 small-R jet (0.4)**



Large-R jet (Higgs Candidate)

- **Consistent with two-pronged H(bb) decay kinematics**
- **Two associated Track Jets**
- **b-tagging performed on the associated Track Jets**

Small-R jet

- **Large angular separation from Higgs-Candidate ($\Delta R > 2$)**
- **One associated Track Jet**
- **b-tagging performed on the Track Jet**

Dictionary: TRACK JETS

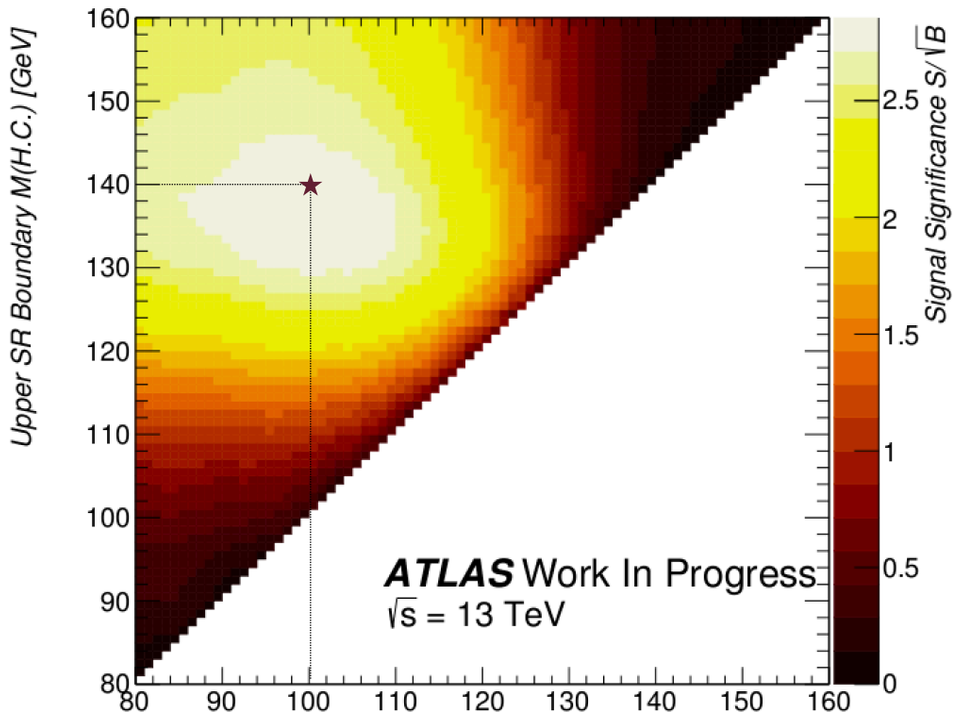
Jets reconstructed out of particle tracks, rather than calorimeter deposits. The same algorithm is used.

SENSITIVITY OPTIMIZATION

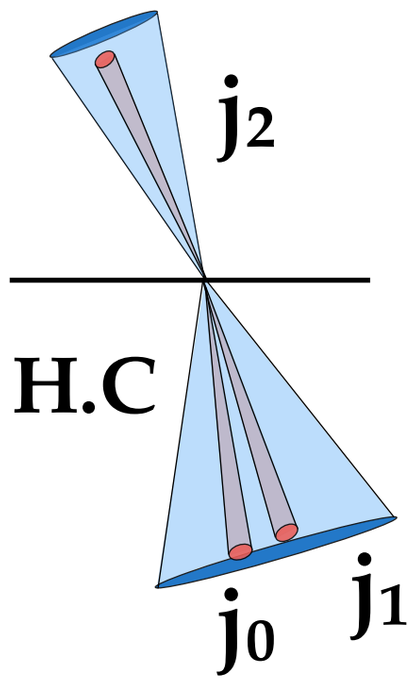
- **Signal Region definition on Higgs Candidate (H.C.) mass**

$$M_{HC} \in [100,\ 140]\ \text{GeV}$$

- **<u>Cuts optimised on full background model</u> in Signal Region**



- **<u>Kinematic Selection</u>**
  - **<u>Trigger</u>: lowest unprescaled single large-R jet trigger per year**
  - **Requirements on Jet pT to match the trigger**
- **<u>Geometric Selection</u>**
  - **Angle between TrackJets in Higgs Candidate**
  - **Angle between Small-R Jet and Higgs Candidate**
  - **One or more extra Jets in the forward detector region**
  - **Top Background Suppression**

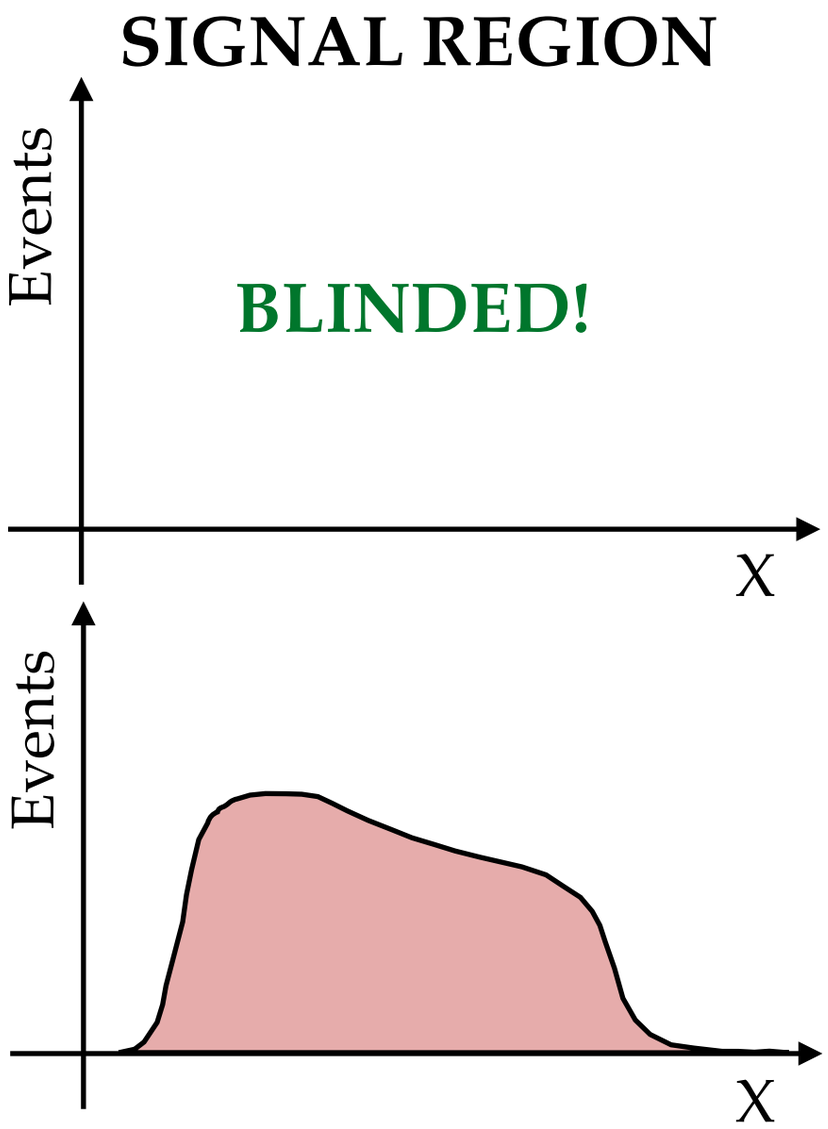


BACKGROUND MODELLING

- **Fully hadronic final stat + lepton veto + top suppression**
  - **background mostly from QCD Multi Jet production**
- **<u>Fully data-driven background estimation:</u>**
  - **Reproduce features of blinded data from orthogonal sample**
  - **Reweighting kinematic distributions in a dedicated Control Region**

High Purity Sample
(<u>3 b-Tags</u>)

Low Purity Sample
(<u>2 b-Tags</u>)



If high-purity data is blinded, what is there to do?

BACKGROUND MODELLING

- **Fully hadronic final stat + lepton veto + top suppression**
  - **background mostly from QCD Multi Jet production**
- **<u>Fully data-driven background estimation:</u>**
  - **Reproduce features of blinded data from orthogonal sample**
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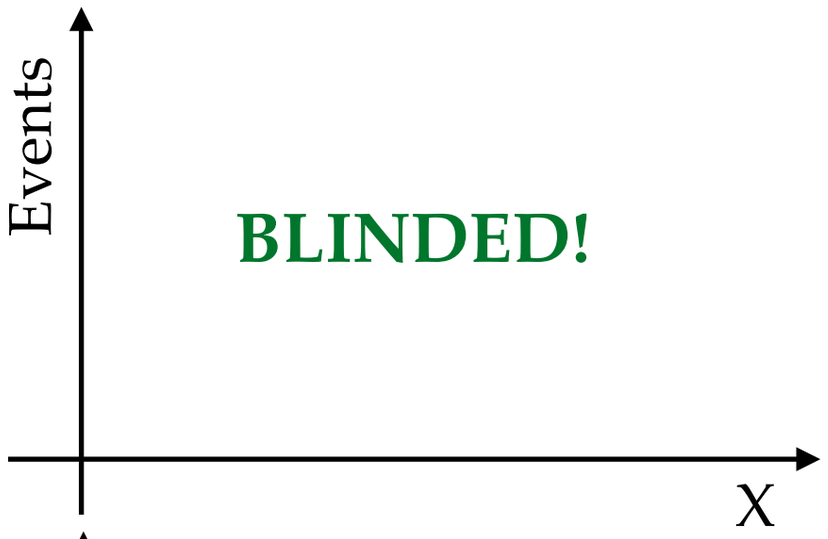
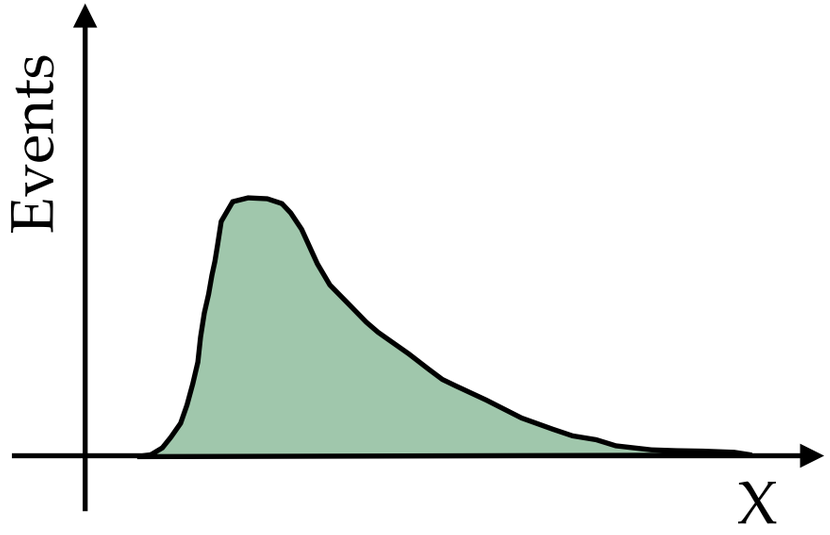
SIGNAL REGION

CONTROL REGION

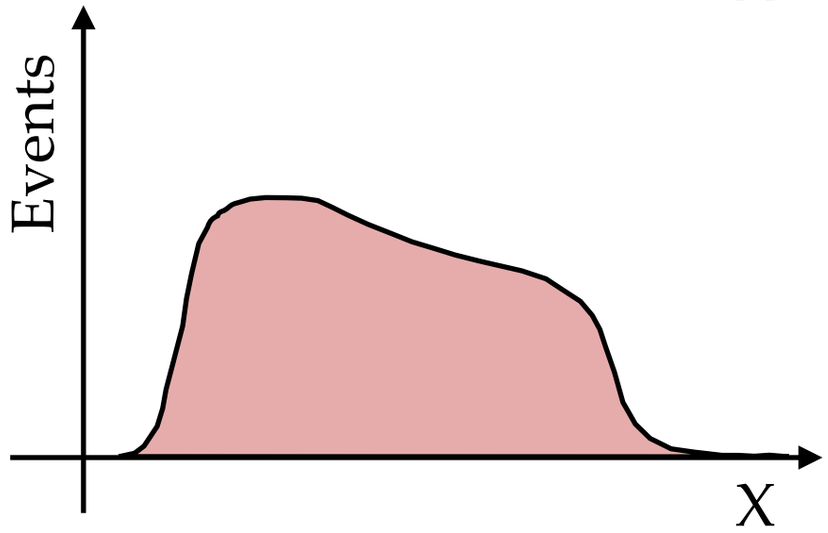
High Purity Sample
(<u>3 b-Tags</u>)

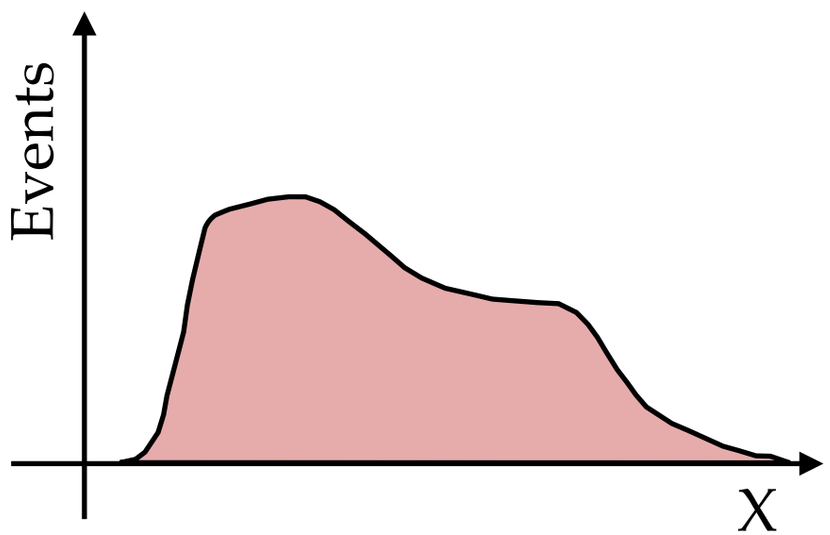


BLINDED!



Low Purity Sample
(<u>2 b-Tags</u>)



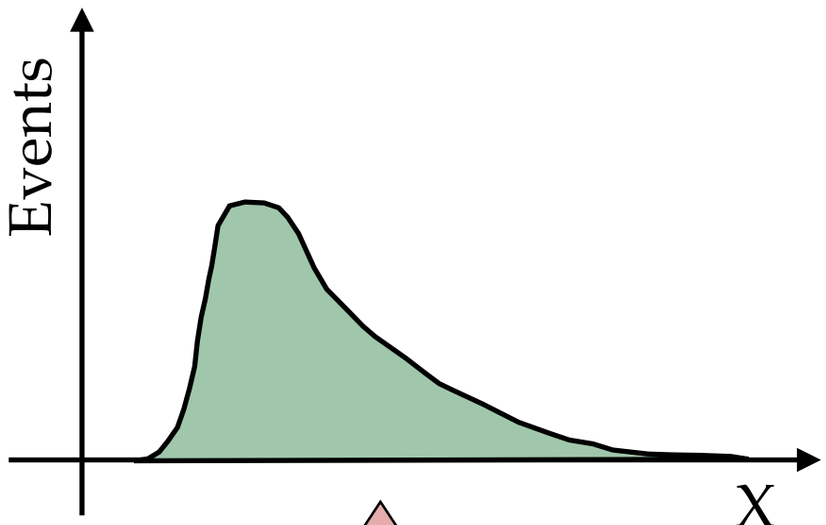


BACKGROUND MODELLING

- **Modelling procedure in a nutshell:**

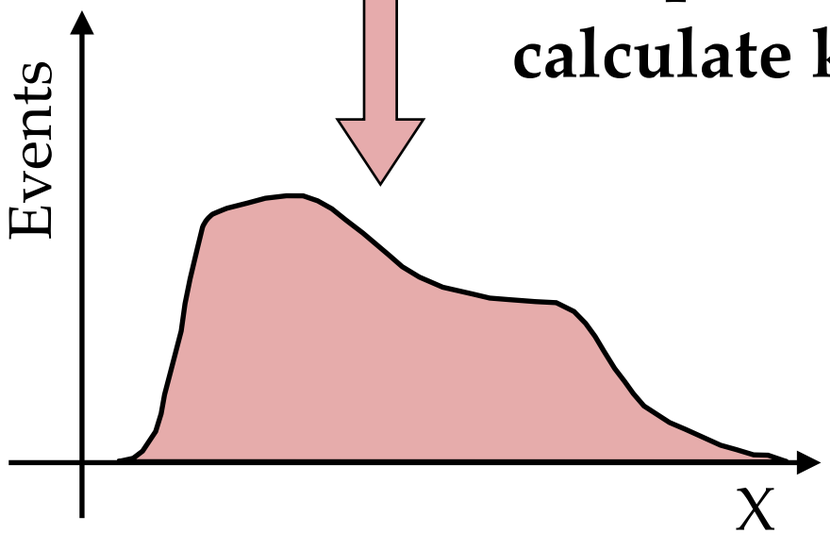
CONTROL REGION

3 b-Tags



Compare distributions and calculate kinematic weights

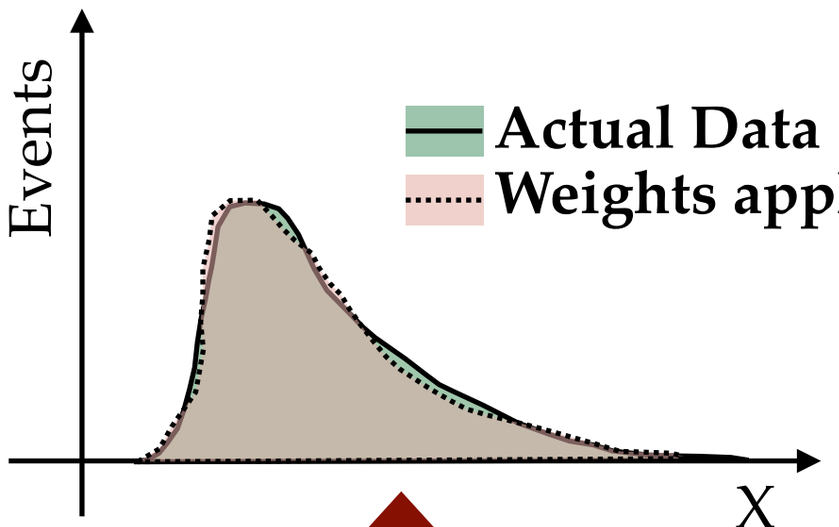
2 b-Tags



- **Modelling procedure in a nutshell:**

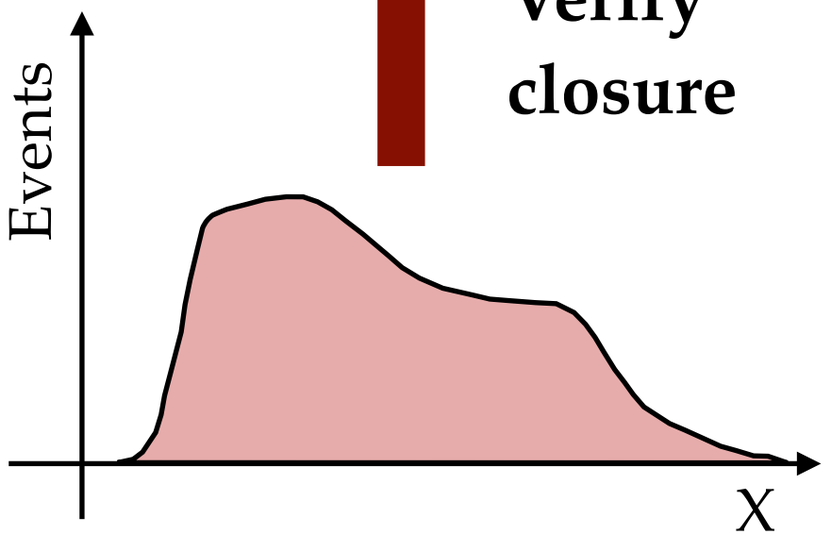
CONTROL REGION

3 b-Tags



Verify closure

2 b-Tags



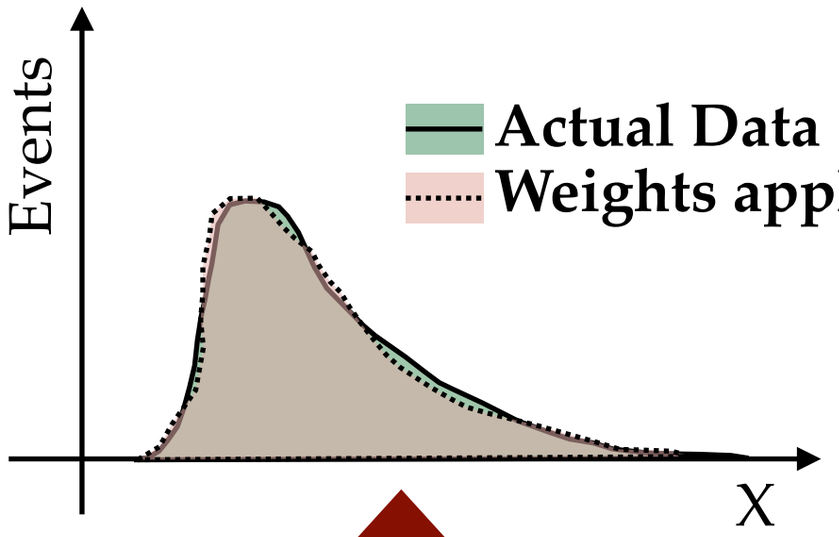
BACKGROUND MODELLING

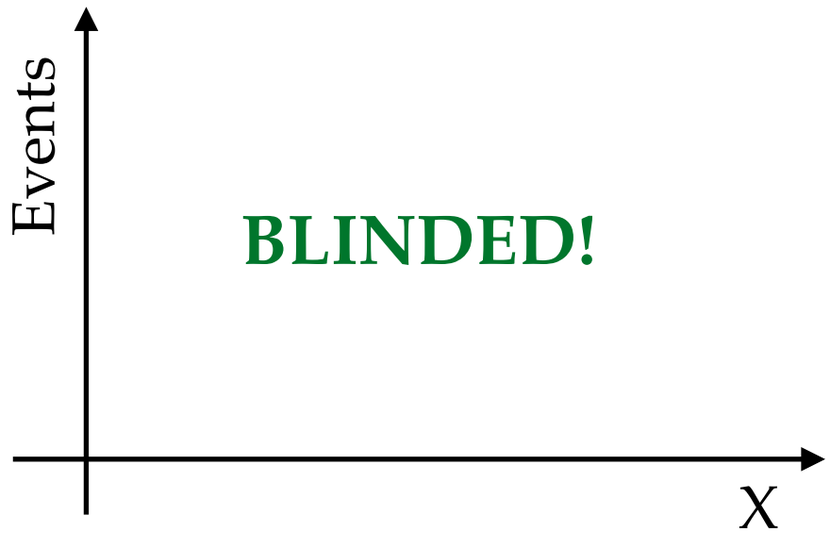
- **Modelling procedure in a nutshell:**

CONTROL REGION

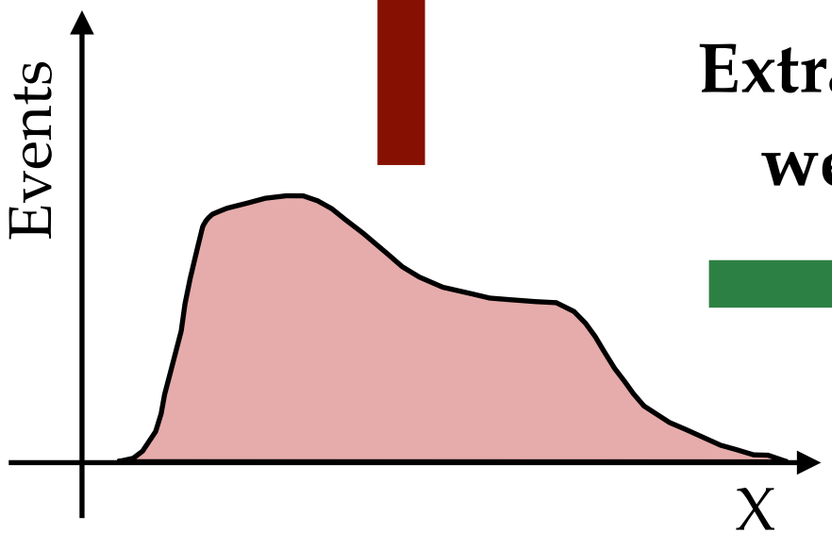
SIGNAL REGION

3 b-Tags

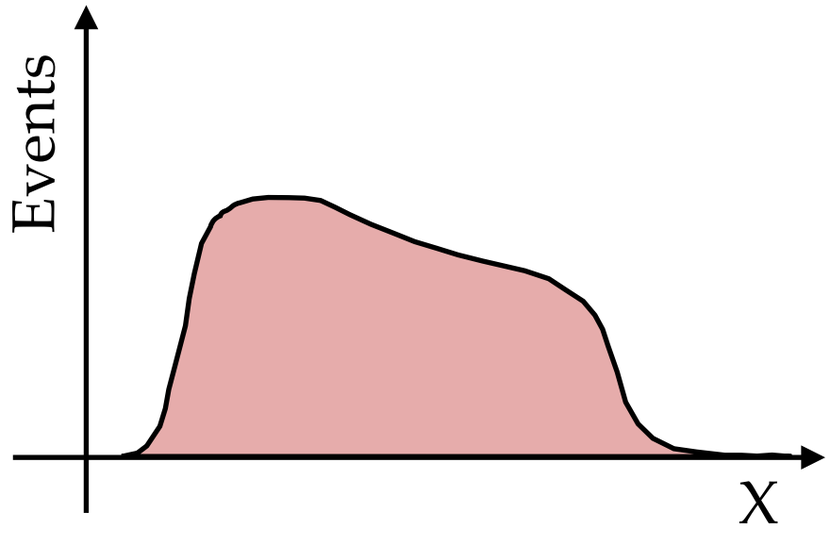




2 b-Tags

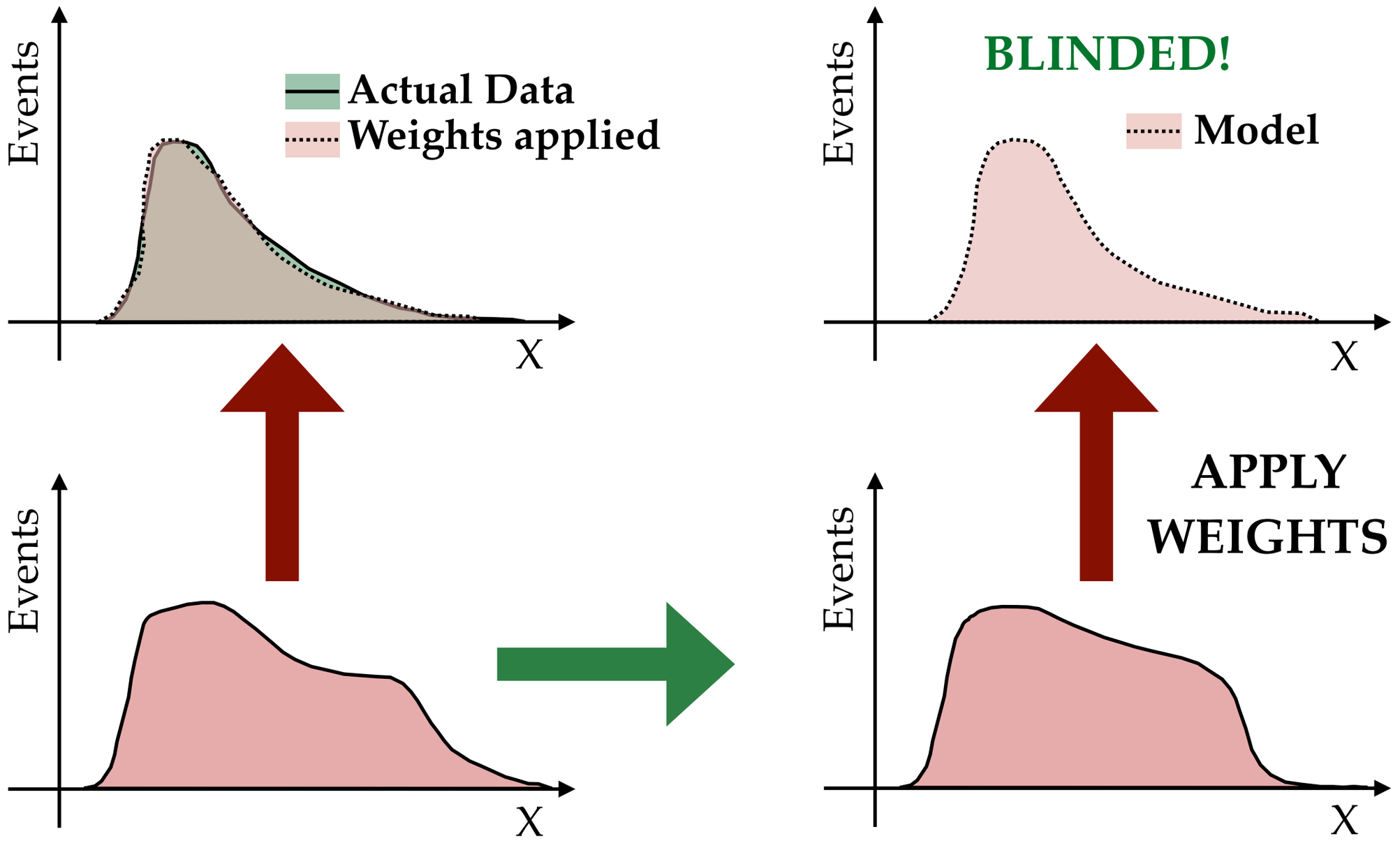


Extrapolate weights

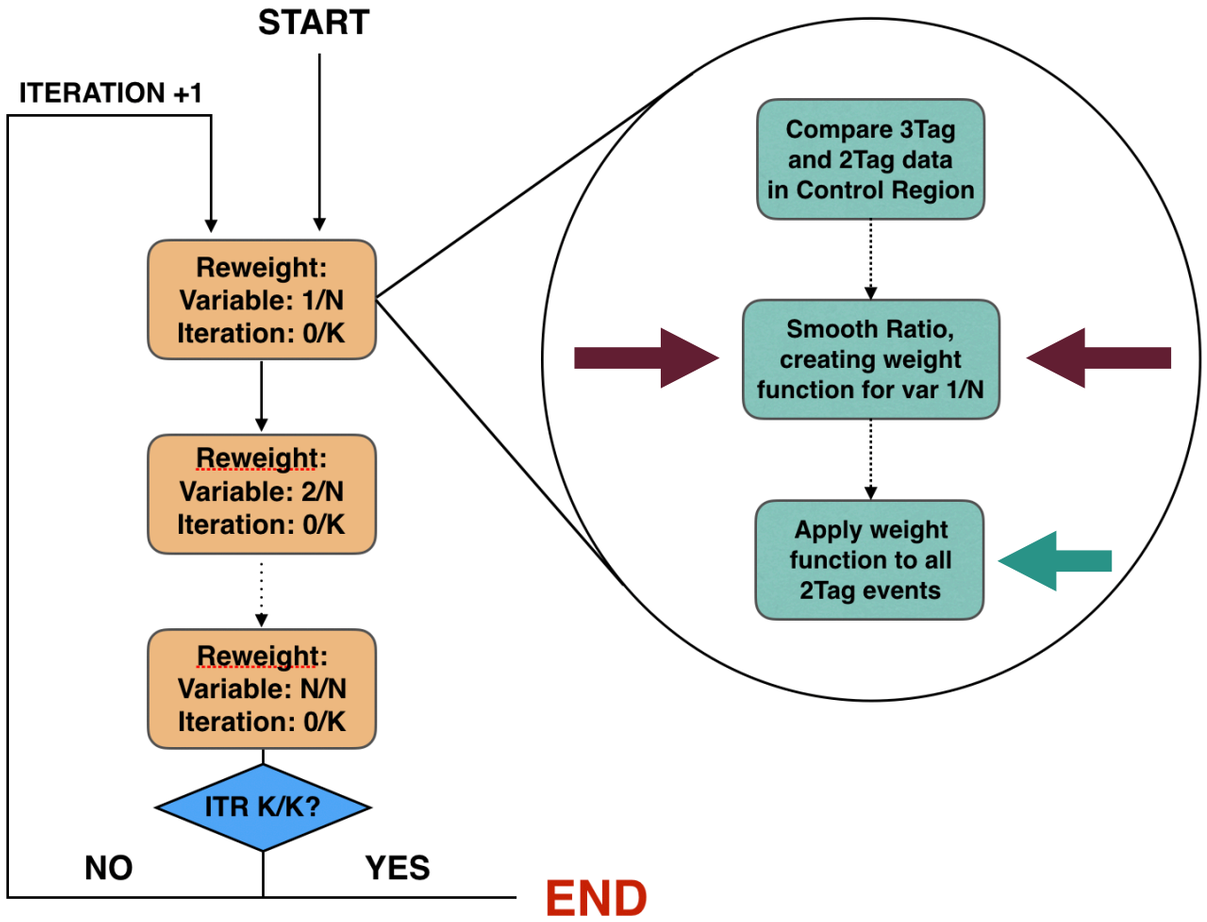


BACKGROUND MODELLING

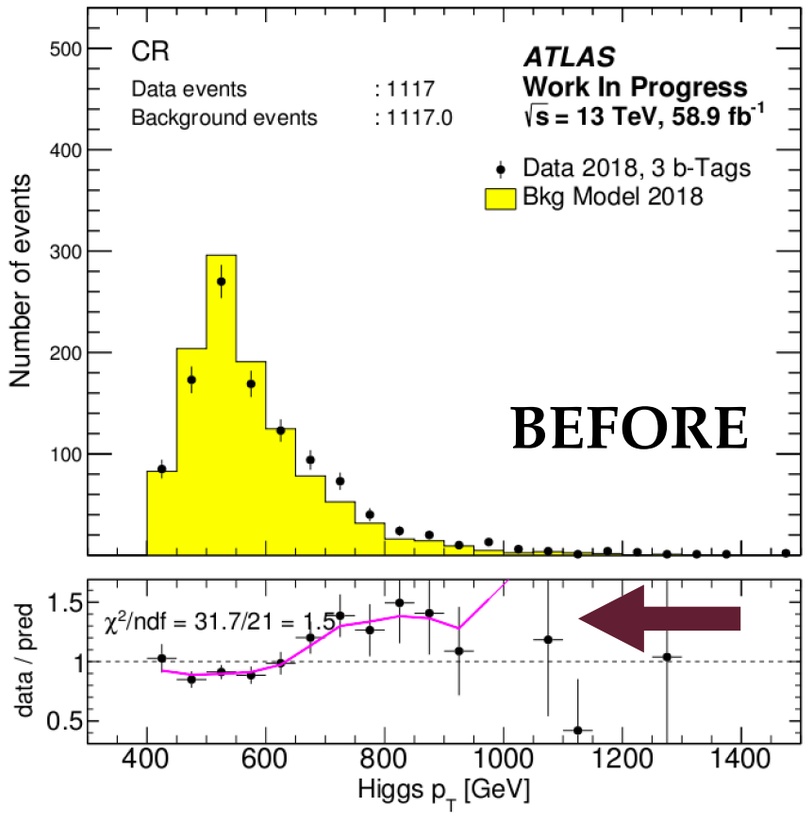
- **Modelling procedure in a nutshell:**

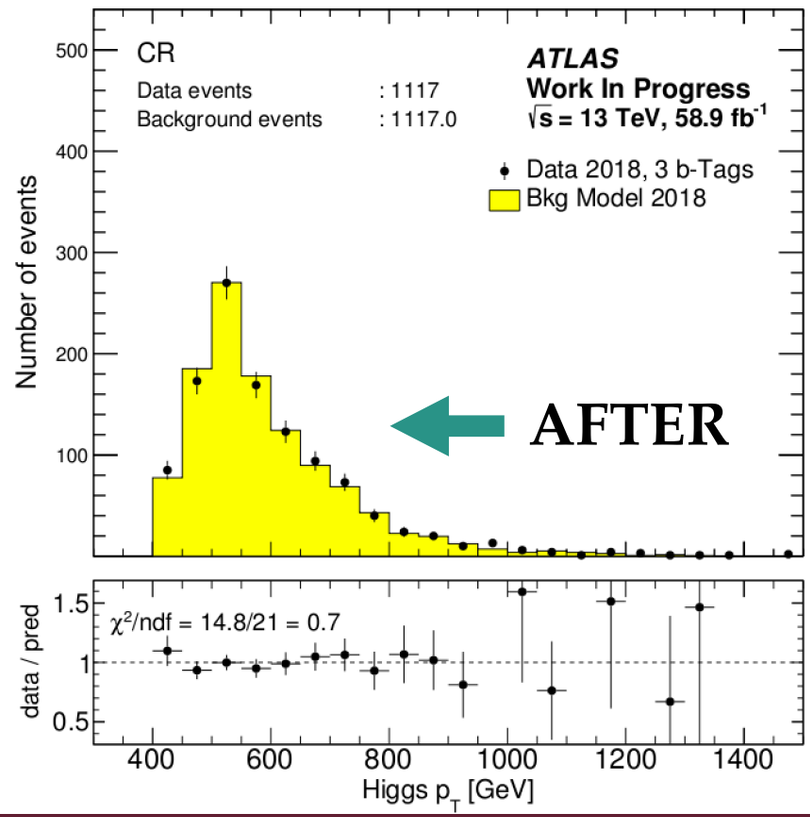


WEIGHTS CALCULATION



$$W = \underbrace{\mu_{QCD}}_{\text{yield SF}} \times \underbrace{\prod_{k} w_k}_{\text{shape factor}} \qquad k \in variables$$





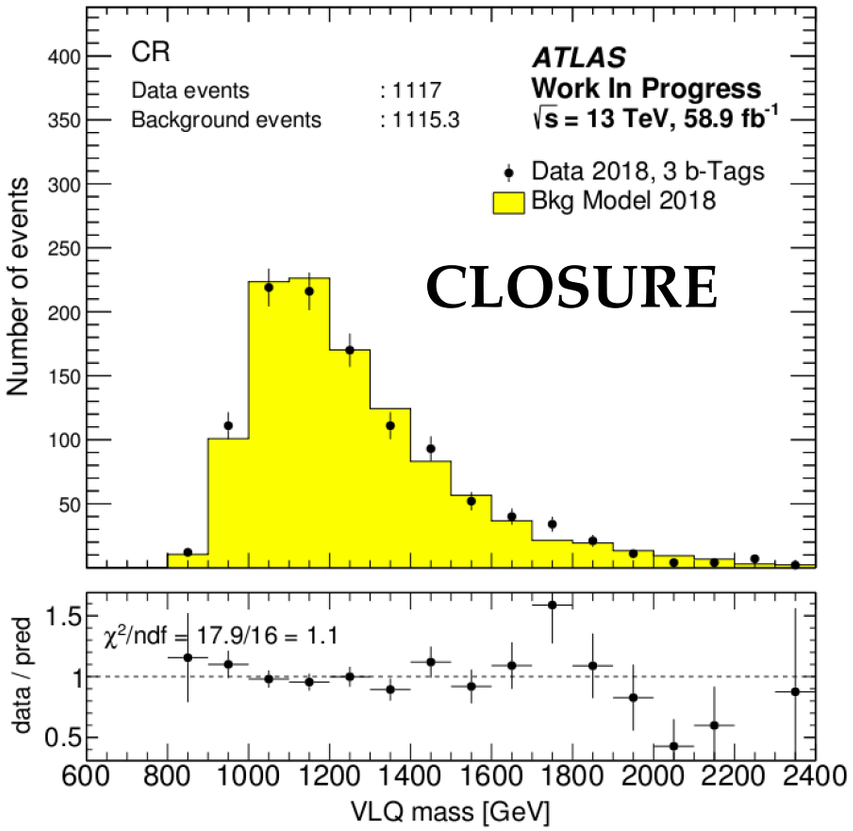
- **Weight Smoothing: Kernel Density Estimation**
- **Chi squared threshold to stop iterations**

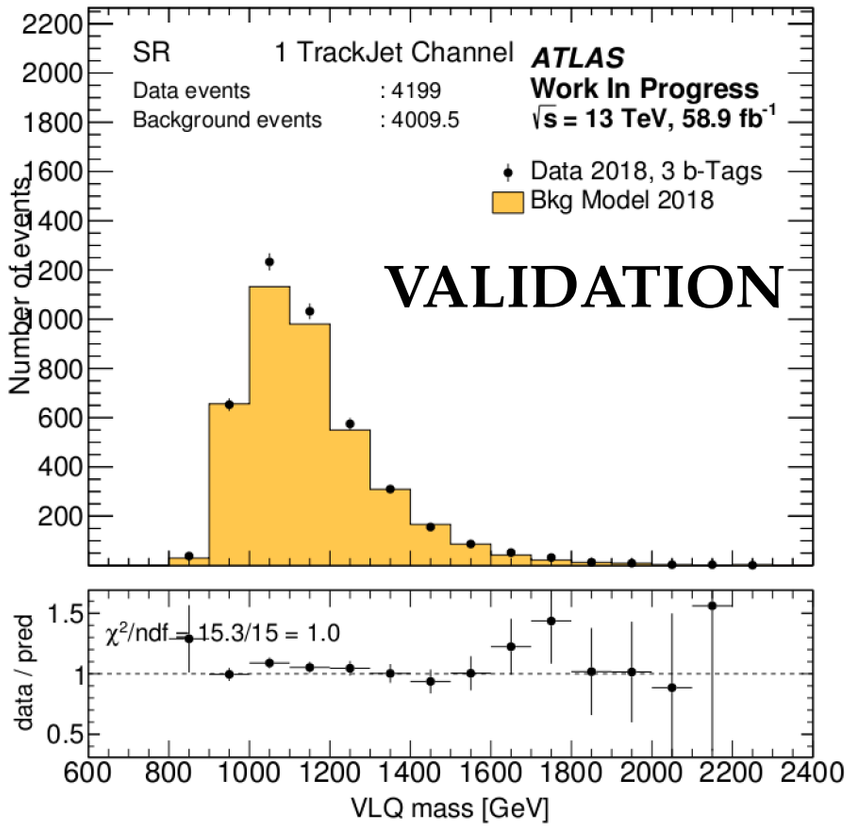
MODEL VALIDATION

- **Points of concern:**
  - **Validate the weight extrapolation to the Signal Region**
  - **Stability WRT statistical fluctuations**

VALIDATION

- **Unblind NON sensitive channel (1 TrackJet in Higgs Candidate)**
- **Apply modelling and compare with Signal Region data**
- **Apply consistent yield discrepancy as systematic on normalisation**





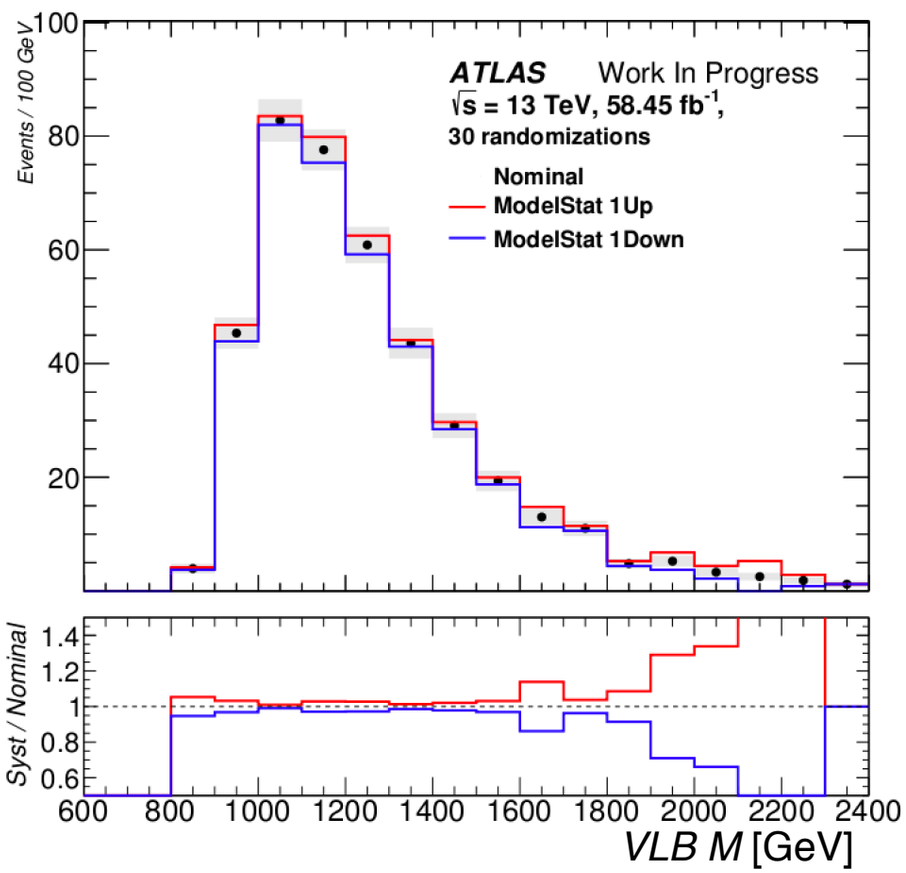
- **Acceptable shape agreement**
- **slight yield underestimation**

MODEL VALIDATION

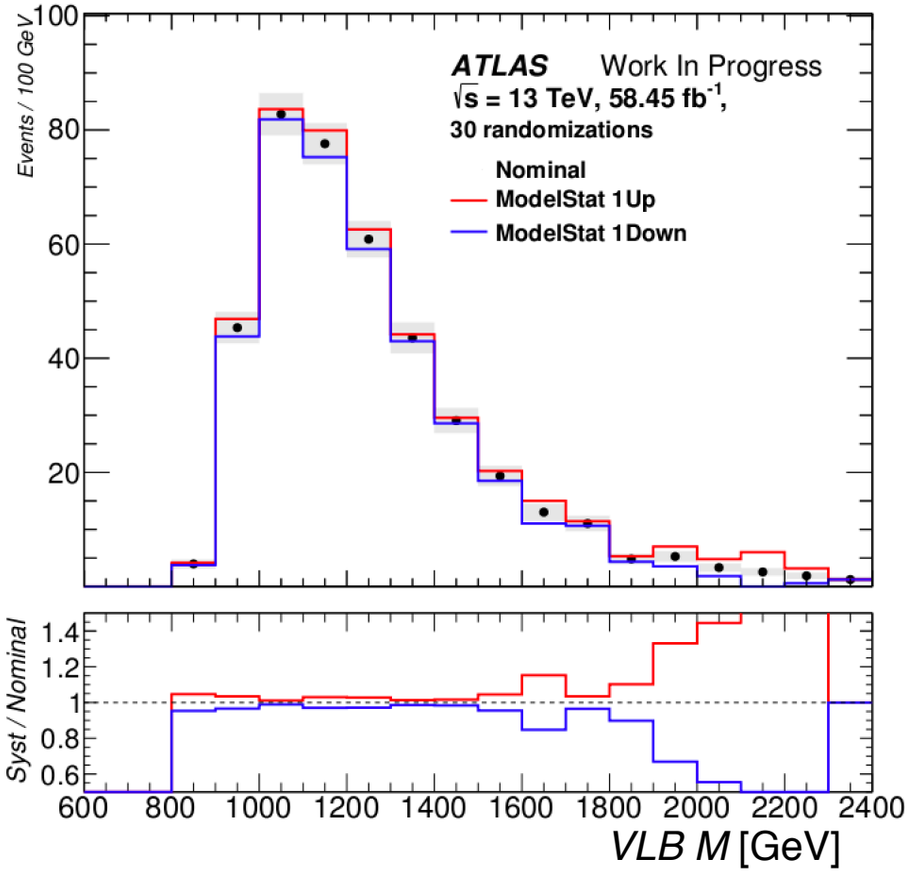
- **Points of concern:**
  - **Validate the weight extrapolation to the Signal Region**
  - **Stability WRT statistical fluctuations**

STABILITY

- **Produce toys varying the 3-Tags histogram of one/two input variable**
- **Systematic = envelope of all models in the final observable M_{VLB}**



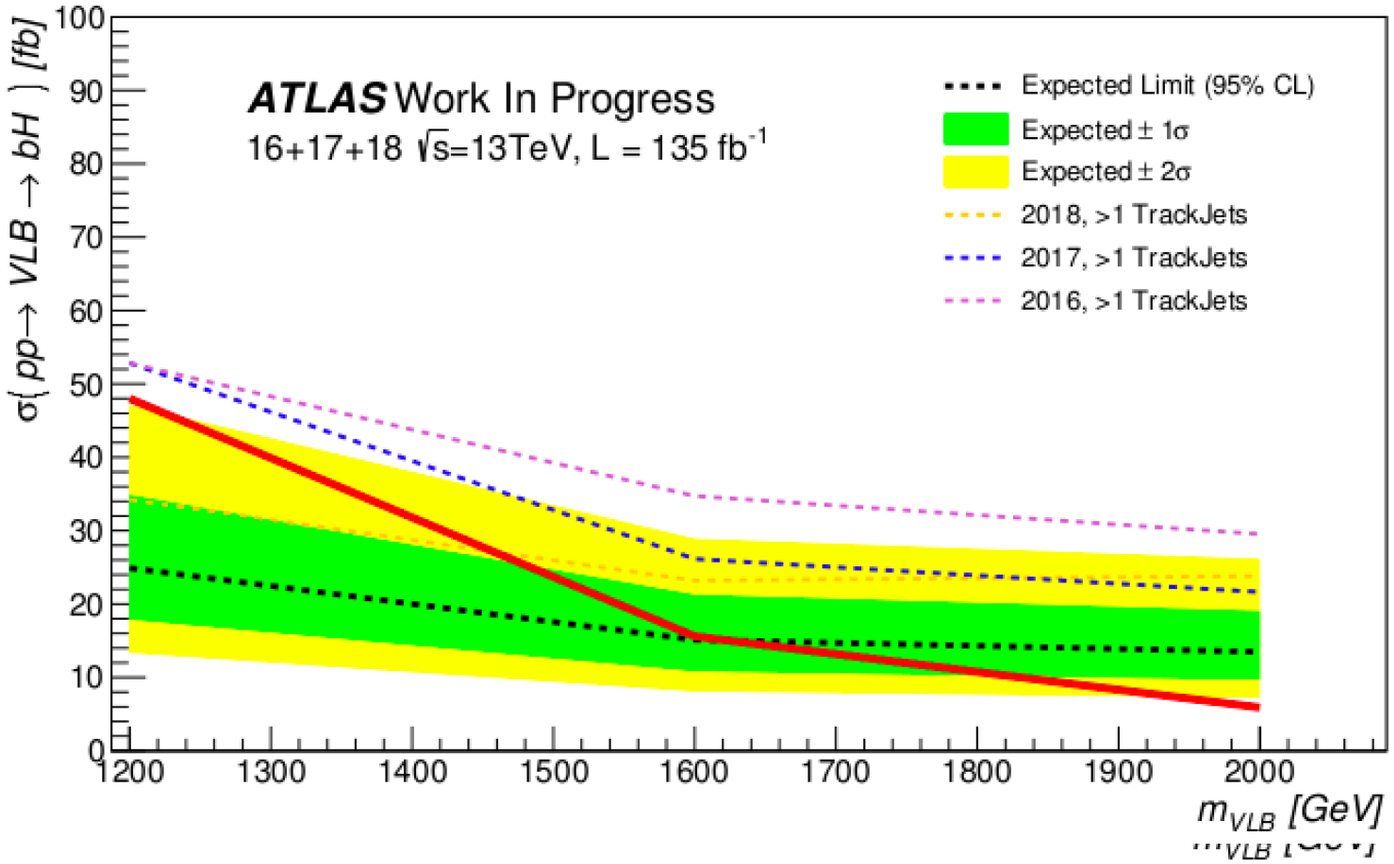
1 input histogram randomised



2 input histograms randomised

PRELIMINARY RESULTS

- **VERY PRELIMINARY Results:**



- **Expected exclusion at ~1600 GeV**
- **Misses: Sysetmatics on the signal**
- **Refinement of modelling systematics (validation)**

More work to be done here!

OUTLOOK

- **Mature analysis:**
  - **Event Selection + Background modelling complete**
  - **Background model is being validated**
  - **Systematic uncertainties on the model being produced**
  - **Limit Setting procedure in place and running**
  - **Approaching internal review phase**

- **Timeline/Goal:**
  - **Publication by end of year**

- **Thanks for listening!**

BACKUP

THEORY SUPPLEMENT

- **VLQs can occur as <u>singlets</u>, <u>doublets</u> or <u>triplets</u>.**
- **Fractional charge**
- **T,B are the 3rd generation quark equivalent**
- **Small mass split between VLQs, decay cascade FORBIDDEN**
- **Decays must involve 3rd generation quarks**

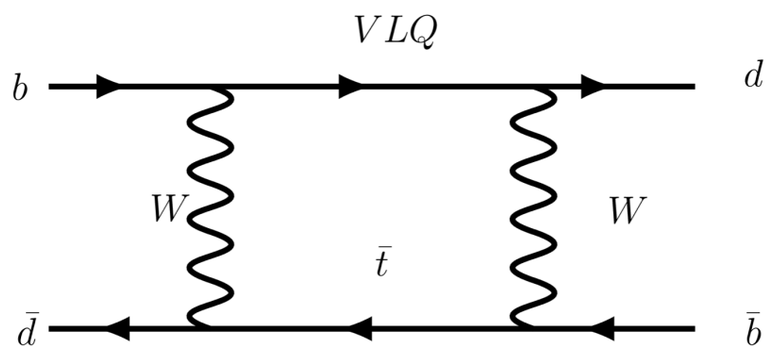
$T_{L,R}B_{L,R}$

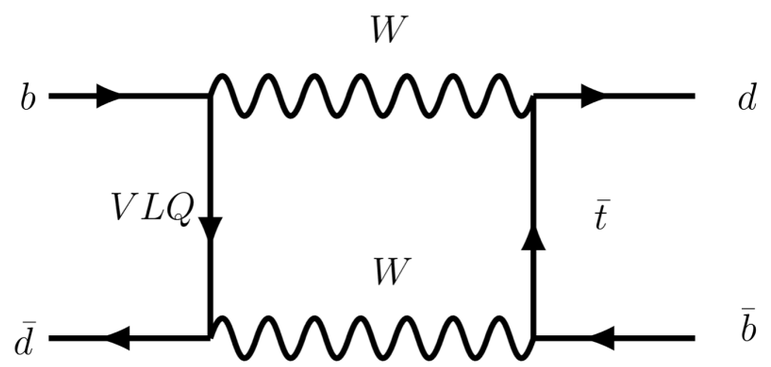
$(X,T)_{L,R}\ \ (T,B)_{L,R}\ \ (B,Y)_{L,R}$

$(X,T,B)_{L,R}(T,B,Y)_{L,R}$

$Q_X = +5/3 \quad Q_T = +2/3$

$Q_Y = -1/3 \quad Q_Y = -4/3$



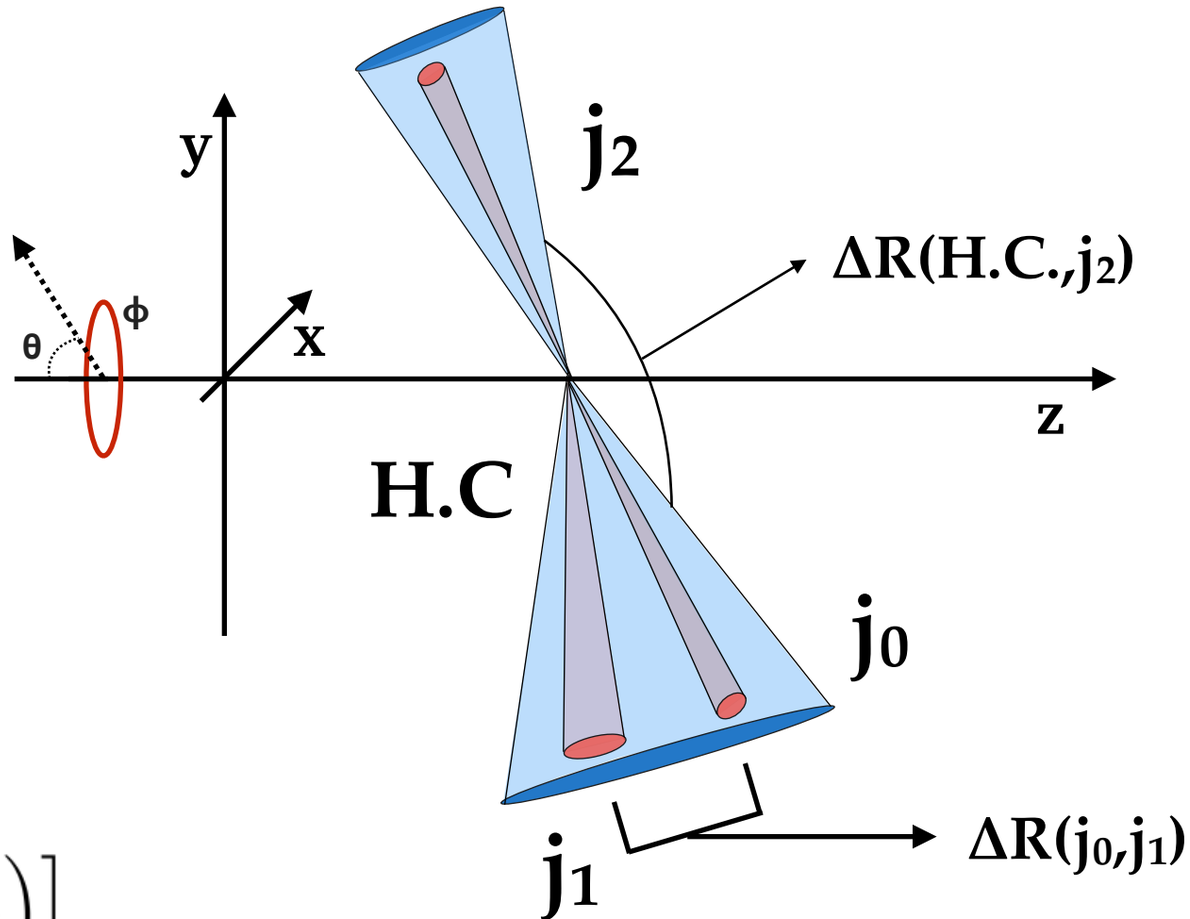


CP Violation

- **Introduced in the B0 mixing system**
- **Easy to visualise from Box Diagrams**
- **Contribution of VLQ in addition to that of SM quarks**

FULL SELECTION

- **Kinematic Selection**
  - **Trigger: HLT_j460_a10t_lcw_jes_L1J100 for 2017-8**
  - **Trigger: HLT_j420_a10_lcw__L1J100 for 2016**
  - **Large-R jet pT > 480 GeV**
  - **Higgs Candidate pT > 200 GeV**
  - **Lepton Veto**
- **Geometric Selection**
  - **> 0 forward jets ($|\eta| > 2.5$)**
  - **$\Delta\eta(H.C, j_2) > 1.25$**
  - **$\Delta R(j_0,j_1)/\min[R_{j0},R_{j1}] > 0.6$**
  - **Top Veto**



Legend

- **η = Pseudo-Rapidity** $\eta \equiv -\ln\left[\tan\left(\frac{\theta}{2}\right)\right]$
- **φ = Azimuth angle**
- **ΔR = Geometric distance** $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$
- **R_{j0} = Radius of Jet0**
- **pT = Transverse momentum** $p_T = \sqrt{p_x^2 + p_y^2}$