Leptoquarks and τ-ID with the ATLAS Detector

Mehul G Depala

University of Liverpool

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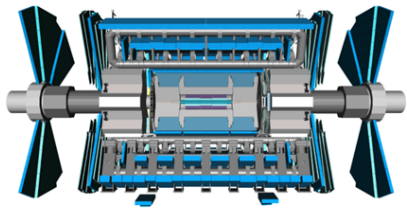
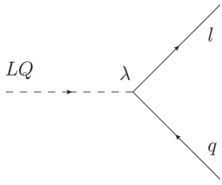
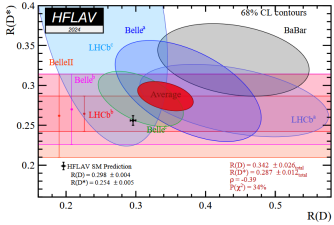
Supervisors: Prof Andrew Mehta (P), Prof Monica D'Onofrio (S), Dr Jordy Degens



Leptoquarks: What are they? Why are they interesting?

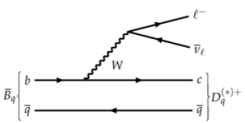
- Hypothetical particles with both baryon and lepton quantum numbers
- Provide a link between similar structure of lepton and quark families

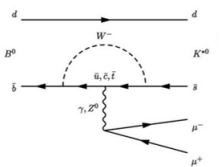


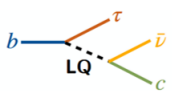


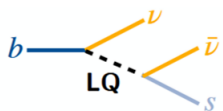
Motivations:

- General class of BSM models predict states with LQ properties: GUT, Pati-Salam, Technicolour
- B-Anomalies measured at LHC-b, BaBar & Belle
  - SM prediction of FCNC is a loop diagram
  - LQ mediator would be Tree level process

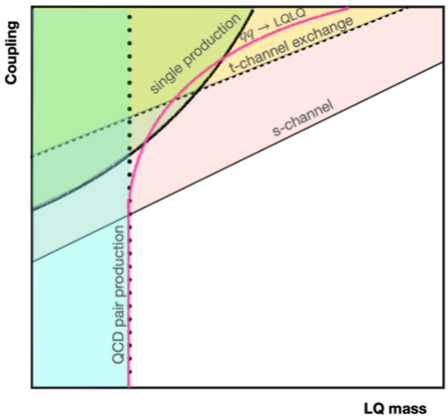




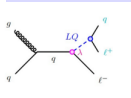




Leptoquarks: Overview

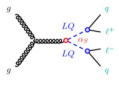


Single Production



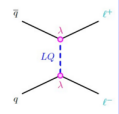
- σ is dependent on mass and coupling (λ) coupling
- Drives sensitivity to higher LQ mass

Pair-Production



- σ is dependent on mass only

Non-resonant



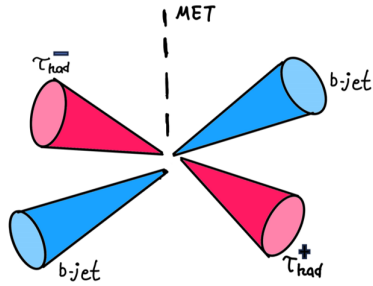
- σ is $\propto \lambda^4$
- Depends on quark-PDF squared

Analysis Goals & Event Topology

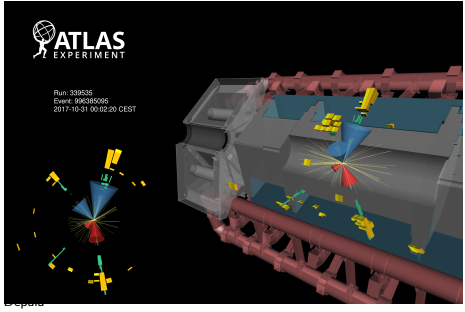
Analysis will focus on 3$^{\mathrm{rd}}$gen coupling (Γ (decay rate) is $\propto$ CKM matrix elements)

Event Topology:

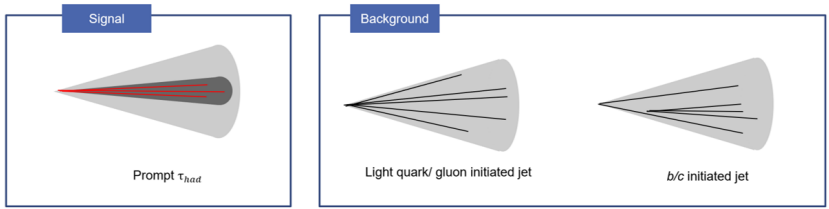
- 2-b jets
- 2-τ_{had}-tagged jets (Opposite-sign)
- E_T^{miss}



- Exploit the better τ/b-jet tagging algorithms
- Higher CoM energies
- More data (Run 2 $\sim 140\mathrm{fb}^{-1}$, Run 3 (2022-24) $\sim 165\mathrm{fb}^{-1}$)
- Targeted analysis for the high-p_{T} phase-space



Intermezzo: τ-Identification



Properties:

- Mass: 1.8 GeV ($\sim 3500\, m_e$)
- Lifetime: $2.9 \times 10^{-13}\, s$
- Branching fraction: Hadronic $\sim 66\%$ & leptonic $\sim 34\%$
- Categorized into 1-3 prong $\rightarrow n_{\mathrm{charged-tracks}}$

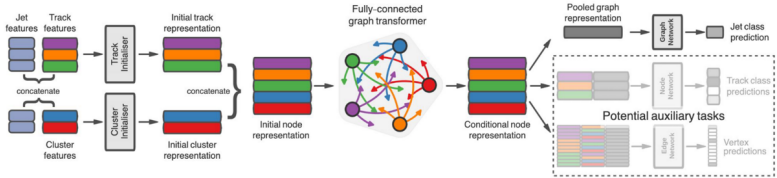
Signatures:

- Secondary vertex
- Jet shape $\rightarrow$ narrower/collimated
- 1/3- reconstructed charge tracks in the "core"-region ($\Delta R \leq 0.25$) of the jet

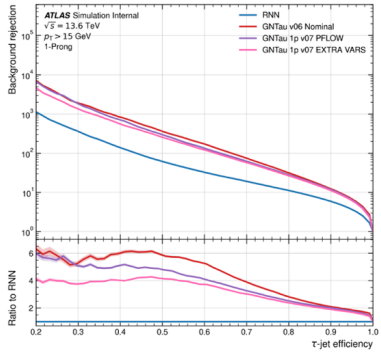
Method:

- Neural network for binary classification task
- Input features: high-level jet variables, track-level features & clusters

Intermezzo: Using Graph Neural Networks/ Transformers

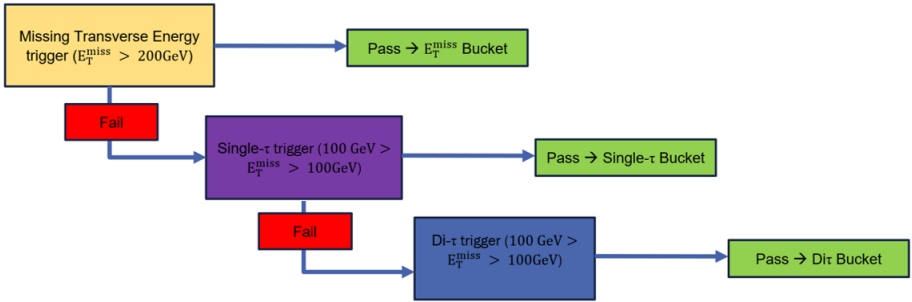


- Transitioning from Recurrent Neural network to graph/transformer architecture
- Allows more natural representation between all objects within the τ_{cand}-jet
- Attention layers learn long term dependencies
- Parallelizable $\rightarrow$ scales with data



- GNN/transformer architecture outperforms RNN (compare to blue curve)
- Performed studies across different configurations/inputs/architectures
- Plot is showing results with a model with additional input features related to information about neutral hadronic objects within the τ_{cand}-jet (purple curve)

Trigger Strategy



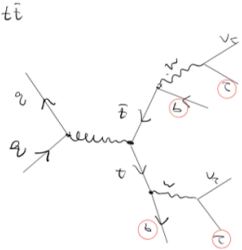
- ATLAS has two-level trigger system for recording events to disk
  - L1: Hardware based trigger
  - HLT: High-level trigger - Software based
- Various different triggers for different physics signatures

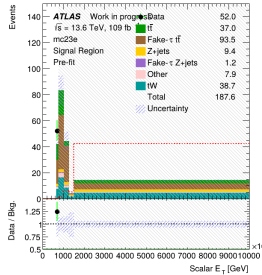
Trigger	Overall Efficiency
MET	95%
STT	75%
DTT	45%
Single Jet	72%
Multi Jet	57%

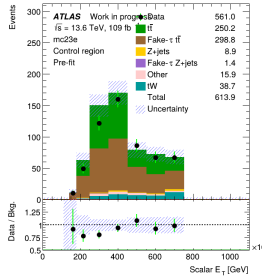
- Conducted studies to determine the most efficient triggers
- Trigger strategy is using "buckets"

Background Modeling

- Dominant backgrounds are: $t\bar{t}$ (same final state - e.g see diagram), $Z + \text{jets}$
- $t\bar{t}$ normalizations are derived from an $e\mu$ Opposite Sign (OS) region
- $Z + \text{jets}$ normalizations are derived from a ee/ $\mu\mu$ OS region
- Normalizations are applied as function jet multiplicity

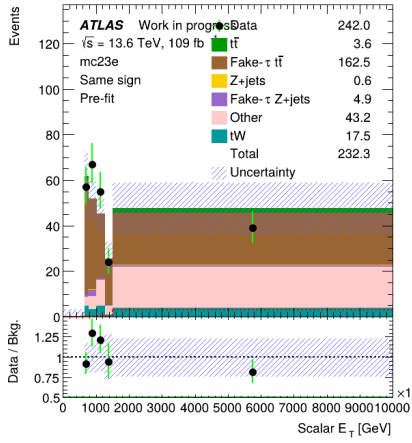






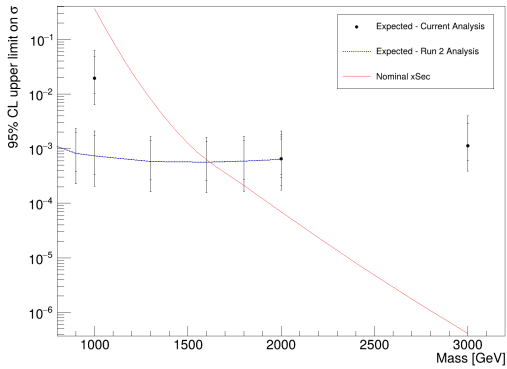
QCD-Jets faking τ's Modeling

- Analyses with τ_{had} must deal with QCD-jets that fake τ's (i.e pass the NN)
- Look at the Same-sign region to estimate the size of this contribution
- Plots show data and MC agree reasonably well $\rightarrow$ indicates the contribution of QCD fake-τ is small
- Overall will use the data-driven method to derive scale factor



Sensitivities

- Plot showing the upper-limit of σ at the 95% CL
- We do not currently have the full signal MC grid (I worked on the validation and this is production in currently)
- Currently sensitivity is worse at lower LQ mass
  - Work in progress
  - Analysis has focused on high p_{T} phase space where statistics are worse and therefore binning is less granular



Conclusions & Summary

Leptoquarks:

- Optimize the sensitivities
- Study on the full MC signal grid
- Systematics

τ-tagging:

- Continue studies on alternative tagger (TauJetGraphs)
- Talk at ATLAS week 2026

Other:

- Completed LTA at CERN
- ATLAS Control Room shifts: Muon, Calorimeter and Run-control/Trigger desk ($\sim$ 30 total shifts)
- CERN tour guide
- Industrial placement

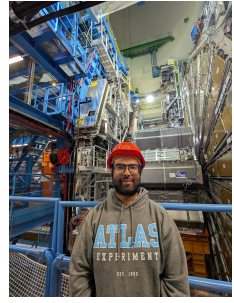


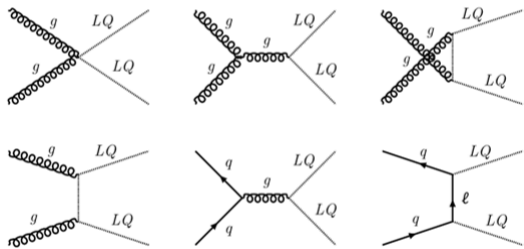
Figure: With the ATLAS detector

Thanks for listening, any questions?

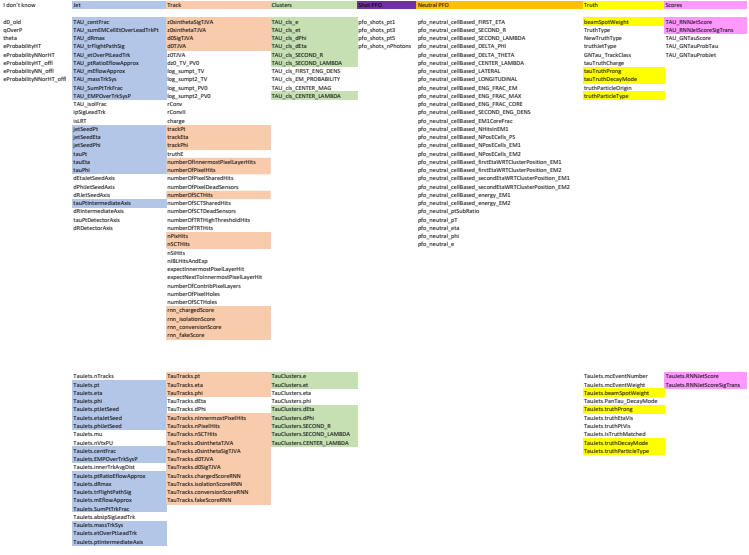
Backup:Leptoquark Model

$$\mathcal{L}_{U_1} = -\frac{1}{2} U^{\dagger}_{1\mu\nu} U_1^{\mu\nu} + M_U^2 U^{\dagger}_{1\mu} U_1^{\mu} - i g_s (1-\kappa_U) U^{\dagger}_{1\mu} T^a U_{1\nu} G^{a\,\mu\nu}$$
$$- i g_Y \frac{2}{3} (1-\tilde{\kappa}_U) U^{\dagger}_{1\mu} U_{1\nu} B^{\mu\nu} + \frac{g_U}{\sqrt{2}} [U_1^{\mu} (\beta_L^{ij} \bar{q}_L^i \gamma_\mu \ell_L^j + \beta_R^{ij} \bar{d}_R^i \gamma_\mu e_R^j) + \text{h.c.}] ,$$

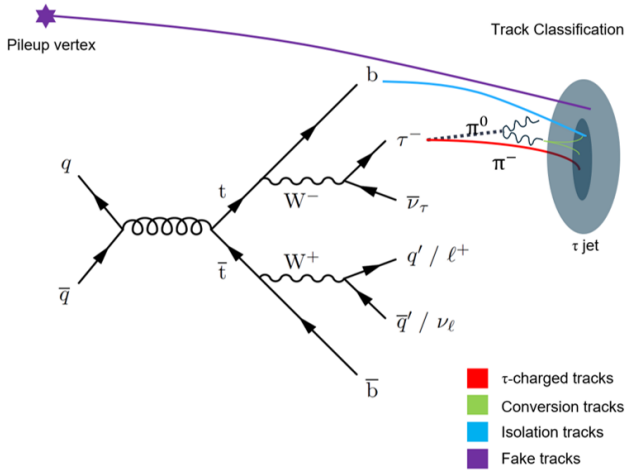
- Effective phenomenological lagrangian for Vector LQ (U1) model
- $\beta_{\mathbf{L/R}}$: Coupling controlling branching fraction to charged/neutral lepton & to LH/RH fermions
- κ_{U} & $\tilde{\kappa_{\mathrm{U}}}$: Coupling to YM/Minimal model $\rightarrow$ overall just enhancement in cross-section



Backup: τ- ID input features



Backup: τ-track classifications



Backup: Cross-Section of LQ

- Cross-section is independent of yukawa coupling to fermions
- Cross-section drops of very quickly as function of mass