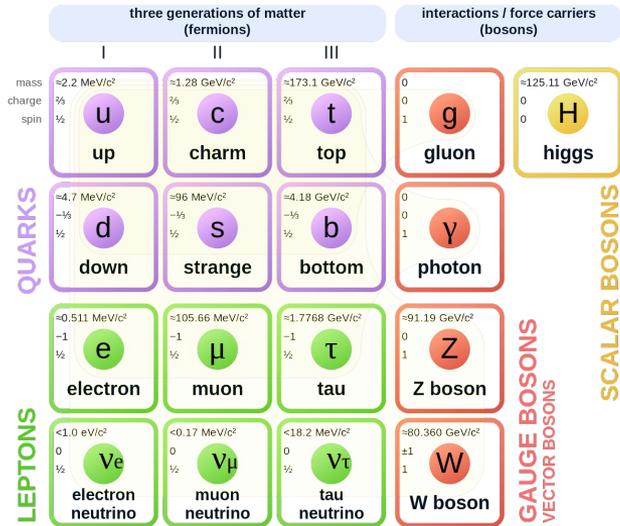


non-resonant vector-like TT to $bW/tH/tZ$ in the fully hadronic final state

Heewon Chung

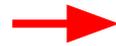
Vector Like Quark: Motivation

Standard Model of Elementary Particles



SM Limitations

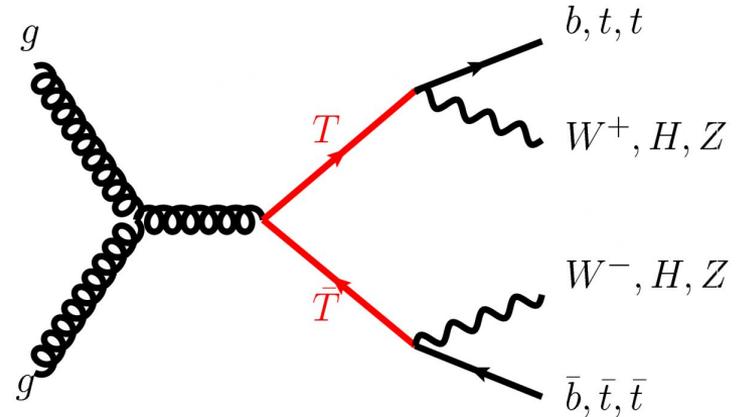
- Muon g-2
- Gauge Hierarchy Problem
- W mass anomaly



New physics model: Vector like Quark

Vector Like Quark

The “**vector-like**” part of their name means that they are not “chiral”. That is, the left-handed and right-handed components of them interact equally with the weak interaction, unlike the real quarks of the Standard Model, where only the left-handed ones do so -> more decay freedom



What is my analysis

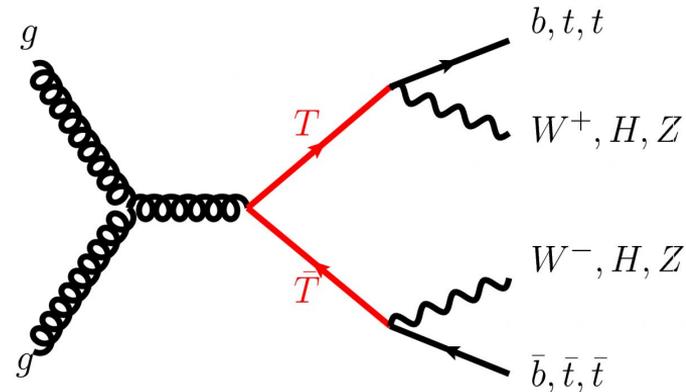
Non resonant VLQ pair production in fully hadronic final state, focus on $T'T'$

Planning to use Run 2 & partial Run 3 data (2022+23+24 — 195 fb⁻¹)

T' has three decay channels $T' \rightarrow Wb$, $T' \rightarrow Zt$ or $T' \rightarrow Ht$.

Branching fraction of T' is $\frac{1}{3}:\frac{1}{3}:\frac{1}{3}$ (model dependent)

Highly boosted events, need new technique



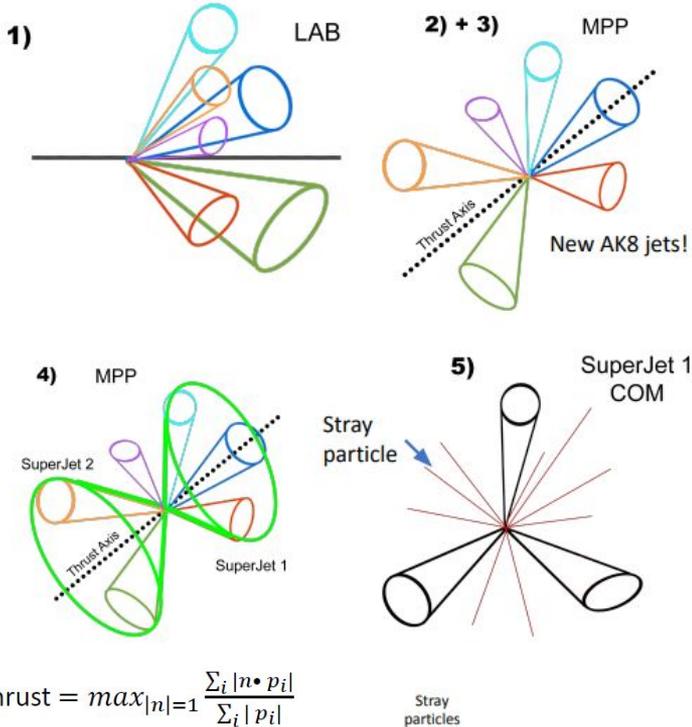
New Strategy: Boosted Jet reclustering technique

Developed by Ethan Caninaert (UCDavis)

- **Goal:** Use event geometry to reconstruct hadronic decays of heavy pair produced signals, and be flexible enough to account for many models and levels of jet merging

- **Algorithm Steps**

1. Select high H_T (> 1.5 TeV) events with many AK8 jets
2. Boost all AK8 jet particles to frame that minimizes parallel momentum (MPP frame).
3. Recluster particles into new MPP AK8 jets
4. Calculate the MPP thrust* axis
 - This should split the event into hemispheres
5. Sort AK8 jets into two “superjets” from their angles relative to the thrust axis.
- 5½. Nearly perpendicular jets chosen to balance superjet mass
6. Boost superjet to its COM & recluster particles into smaller jets



This technique runs in analyzer for reclustering.

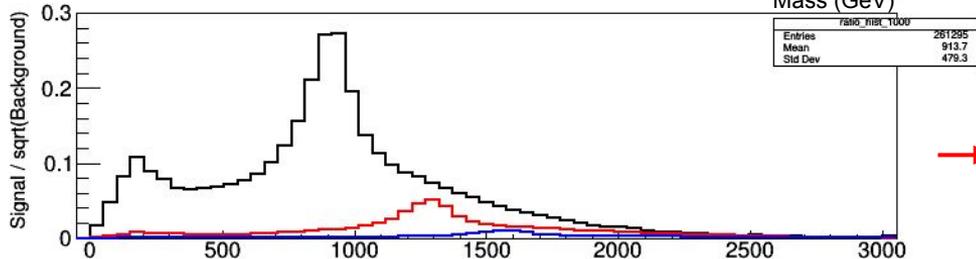
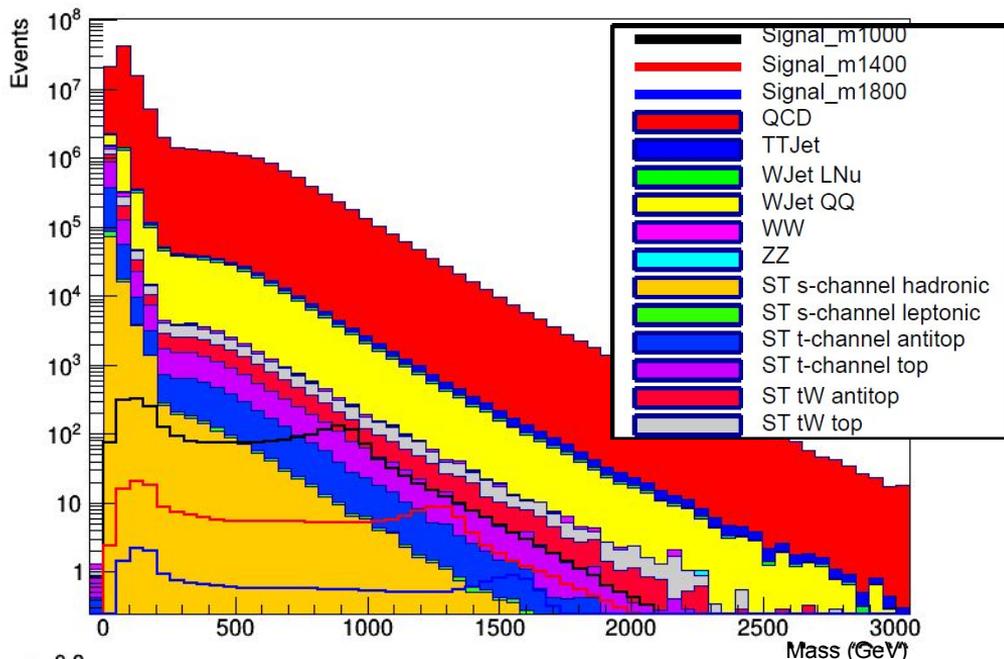
SuperJet is a collection of AK8 jets that are decay products of pair produced particle (T')

This technique will make 2 **SuperJet** in an event.

For preselection we require the AK8 jet $E_t > 150$ GeV
(For preselection we are currently not applying HT cut)

Cut based approach: Superjet mass signal vs backgrounds Preselection sample (2017)

reclustered SuperJet mass (Et 150GeV cut)



Plots are scaled using
2017 lumi = 41.48 fb⁻¹

$$SF = 41.48 \text{ fb} / (N \text{ events} / \text{signal_xs}[\text{fb}])$$

Signal Cross Section used:

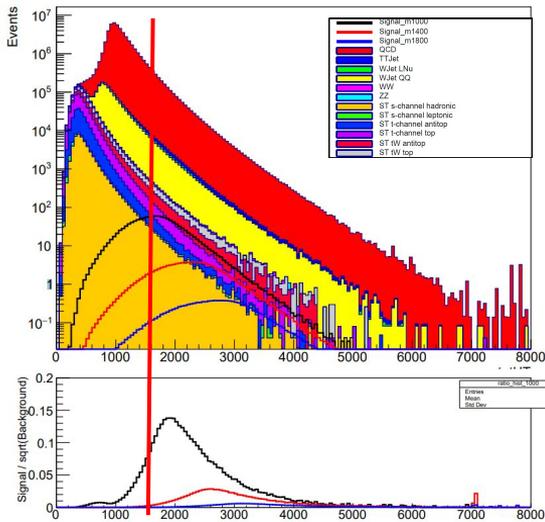
T	13 TeV	13.6 TeV
M1000	25.53 fb	31.34 fb
M1400	2.007 fb	2.596 fb
M1800	0.255 fb	0.3046 fb

→ Poor sensitivity

Selection Cuts

totHT > 1500GeV

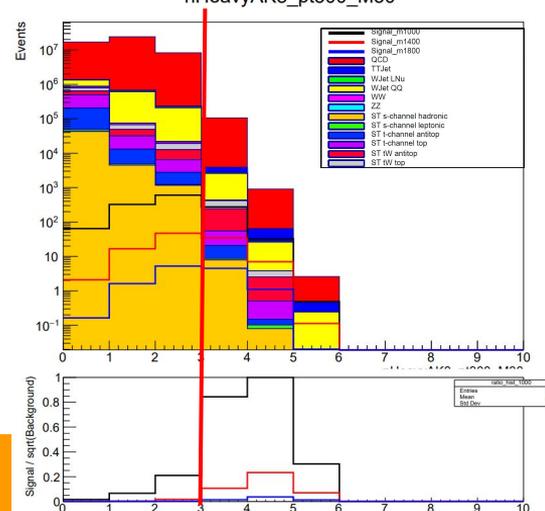
*Total transverse momentum



nHeavyAK8_pt300_M30

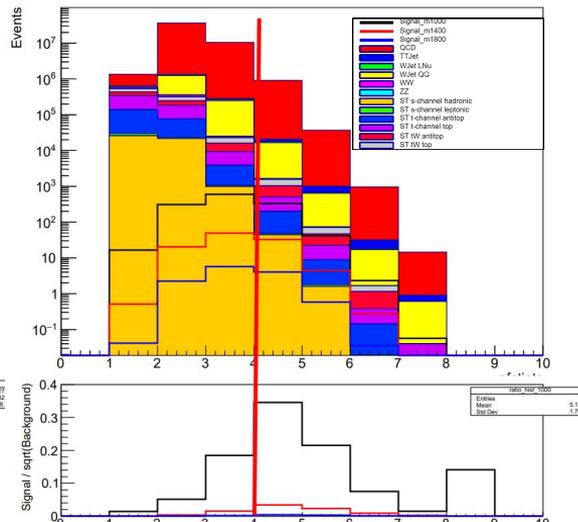
nHeavyAK8_pt
300_M30 > 2

*Heavy AK8 jet : pt greater than 300 GeV & mass greater than 30 GeV



totHT

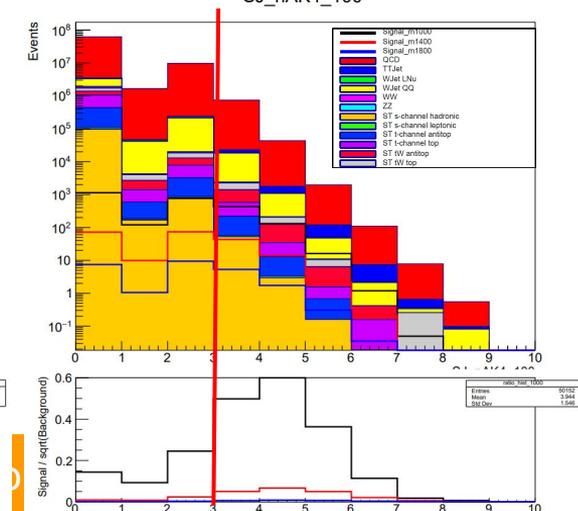
nfatjets



SJ_nAK4_100

nfatjets > 3 (AK8 jets)

*AK8 jets

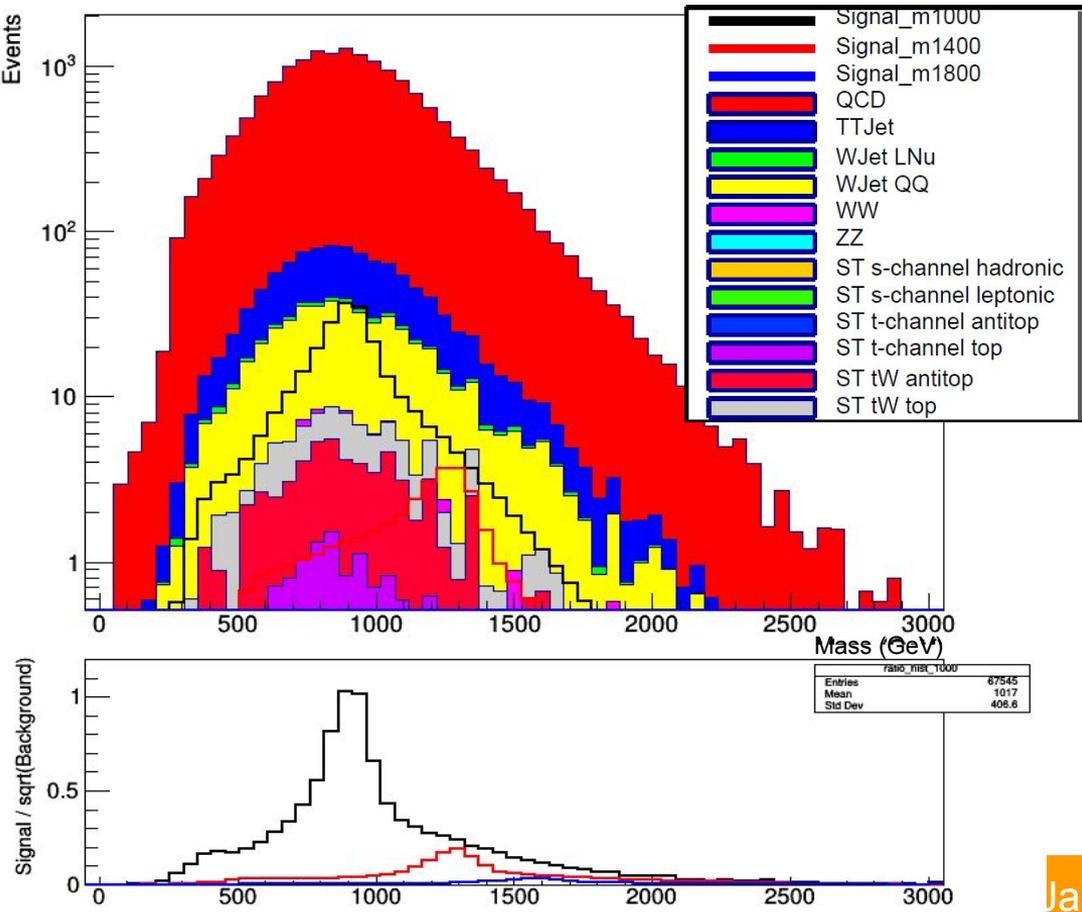


SJ_nAK4_100 > 2

*number of AK4 jets that has E greater than 100 GeV in SJ

Cut based approach: Superjet mass signal vs backgrounds After selection sample (2017)

reclustered SuperJet mass with cuts(Et 150GeV cut)



Data Files	Preselection	Selection	% passed
Signal_m1000	551124	55131	10.0034
Signal_m1400	549616	96102	17.4853
Signal_m1800	551136	108009	19.5975
QCD low	13516817	299	0.0022
QCD mid	12797309	11914	0.0931
QCD high	5842783	21670	0.3709
TTJet low	6567904	55061	0.8383
TTJet mid	1196742	41713	3.4855
TTJet high	652173	47059	7.2157
WJet LNu low	2201190	8	0.0004
WJet LNu mid	2143280	1426	0.0665
WJet LNu high	512888	3197	0.6233
WJet QQ	14367184	2492	0.0173
WW	436360	7	0.0016
ZZ	101633	0	0.0000
ST_s_had	1217858	25	0.0021
ST_s_lep	527252	10	0.0019
ST_t_at	3471830	26	0.0007
ST_t_t	7876402	112	0.0014
ST_tW_at	659857	93	0.0141
ST_tW_t	658715	83	0.0126

Backup

Difference between BEST and Boosted jet reclustering?

BEST method tags lab-frame jets as heavy standard model particles by boosting each jet into candidate rest frames for W,Z,h,t, QCD, and bottom jets. It then calculates a number of BES variables in these frames, and uses these to train a NN that categorizes jets as W,Z,h,t, QCD, or b. Boosted jet reclustering technique differs that it makes no assumptions about any rest frames and instead boosts to the rest frame of the visible mass in the event. This makes it more flexible for studying (pair production) at ultra-high energies where you have jets that are overlapping or where W,b,h,t can be merged or partially merged. BEST would likely not know how to categorize these jets. Our technique is primarily a means to associate AK8 jets with one of two VLQs, so it could be reasonably combined with any of the current analysis metas (Lund plane, BEST, new NNs, etc.)

Gauge hierarchy problem

1. The [electroweak scale](#) is set by the Higgs mechanism, where the Higgs field gives mass to particles. This scale is around $v \sim 246$ GeV, related to the Higgs boson mass (~ 125 GeV).
2. The [Planck scale](#) ($M_{\text{PI}} \sim 10^{19}$ GeV) is the energy scale where quantum gravitational effects become important. It's tied to the fundamental strength of gravity.
3. At the scale of elementary particles, the weak force is billion times stronger than gravity. This is reflected in energy scales.

Weak force: Electroweak scale (~ 100 GeV).

Gravity: Planck scale ($\sim 10^{19}$ GeV).

Gauge hierarchy problem

So how are the Higgs and Planck Scale Difference Related?

The Higgs boson mass (and the electroweak scale) is highly sensitive to the Planck scale because quantum corrections to the Higgs mass depend on the highest energy scale where the Standard Model is valid. These corrections look like this:

$$\Delta m_H^2 \sim \frac{\Lambda^2}{16\pi^2},$$

where Λ is the cutoff scale (usually taken to be the Planck scale, 10^{19} GeV)

To keep the Higgs mass light (~ 125 GeV), you'd need an unnatural cancellation between the large corrections and the "bare" mass of the Higgs.

[Read more](#)

Gauge hierarchy problem

How does VLQ solve this?

In the SM, the top quark gives the largest contribution to the Higgs mass correction:

$$\Delta m_H^2 \sim -\frac{y_t^2}{16\pi^2} \Lambda^2$$

where y_t is the top Yukawa coupling. VLQs with specific couplings to the Higgs can provide positive contributions to this correction:

$$\Delta m_H^2 \sim +\frac{y_{\text{VLQ}}^2}{16\pi^2} \Lambda^2$$

[Read more](#)

Muon g-2

Anomalous magnetic moment of the muon $a_\mu = \frac{g_\mu - 2}{2}$

g_μ : gyromagnetic ratio of the muon

The gyromagnetic ratio g_μ quantifies how the muon's spin interacts with a magnetic field. In the absence of quantum effects, the value of g_μ would be exactly 2.

Quantum effects cause small deviations from this value, known as the anomalous magnetic moment (a_μ), which can be precisely calculated within the Standard Model.

$$\begin{aligned} a_\mu^{\text{SM}} &= a_\mu^{\text{QED}} + a_\mu^{\text{EW}} + a_\mu^{\text{hadron}} \\ &= 0.001\,165\,918\,04(51) \end{aligned}$$

$$a_\mu^{(\text{exp})} = 116\,592\,061(41) \times 10^{-11} \quad \rightarrow 4.2\sigma$$

Fermilab, 2021

W mass anomaly

W mass prediction from SM $M_W^2 = \frac{\pi\alpha}{\sqrt{2}G_F \sin^2 \theta_W (1 - \sin^2 \theta_W)}$

α	fine-structure constant,
G_F	Fermi coupling constant (measured in muon decay)
$\sin^2 \theta_W$	electroweak mixing angle

$$M_W^{(\text{SM})} \approx 80.357 \text{ GeV}$$

However, the measurement from CDF II experiment (Fermilab, 2022)

was $M_W^{(\text{CDF-II})} = 80.4335 \pm 0.0094 \text{ GeV}$.

which is 7σ higher than the SM prediction.

There are some controversies to this result whether the systematic uncertainty was fully considered