

Jet Substructure at the CMS LPC: Building New Algorithms & Searching for New Physics

Justin Pilot

University of California, Davis

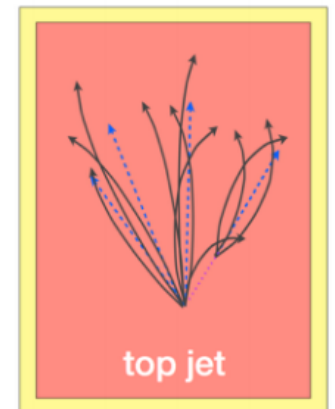
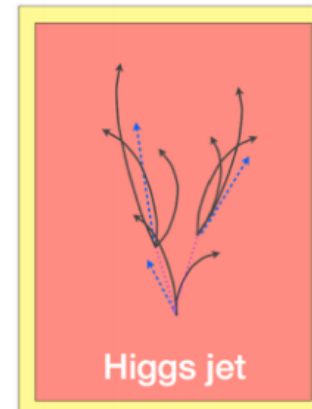
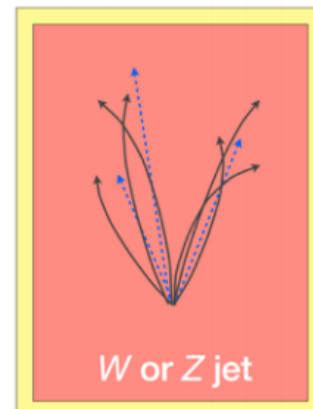
DOE Visit to Fermilab

28 July 2017



Introduction

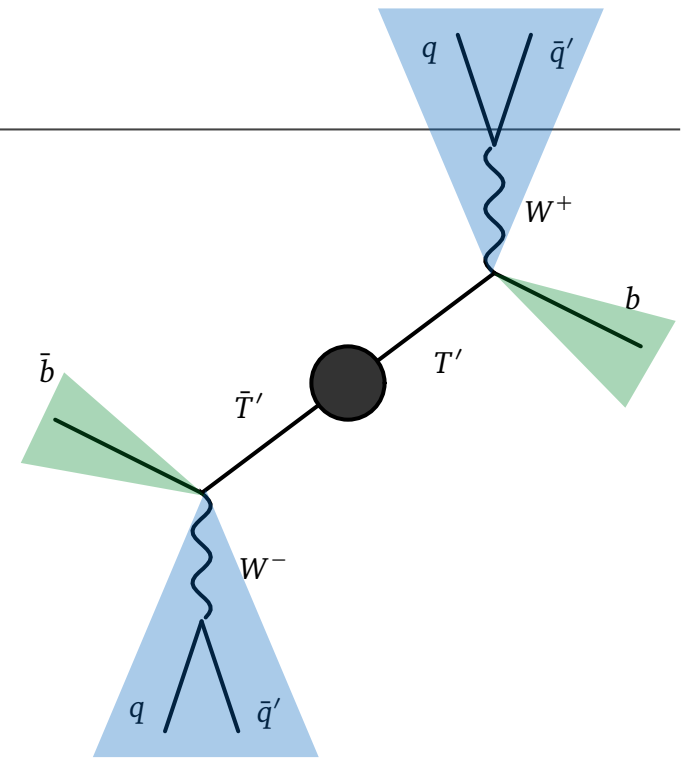
- ▶ I have been a postdoc with UC Davis since January 2012
 - ▶ PhD was on CDF experiment
 - ▶ First exposure to CMS was here at the LPC through the CMS Data Analysis School
 - ▶ Resident at LPC for first few months, then moved to CERN for detector operations
 - ▶ Worked on ME1/1 upgrade project during LS1
 - ▶ Served as Deputy Run Coordinator for the CSC subsystem 2015-2016
- ▶ Involved with LPC activities during my tenure at CERN
 - ▶ DAS instructor, HATS facilitator, workshop participation here at LPC
- ▶ LPC Distinguished Researcher award recipient in 2016
 - ▶ Enhance the jet substructure and B2G-related activities at the LPC
 - ▶ Moved permanently back to LPC Summer 2016, have been based here since then
- ▶ My work currently involves **searches for new physics** using jet substructure signatures in the B2G group and **developing new algorithms** to improve analysis performance



New Physics with Jets

▶ Vector-like quarks

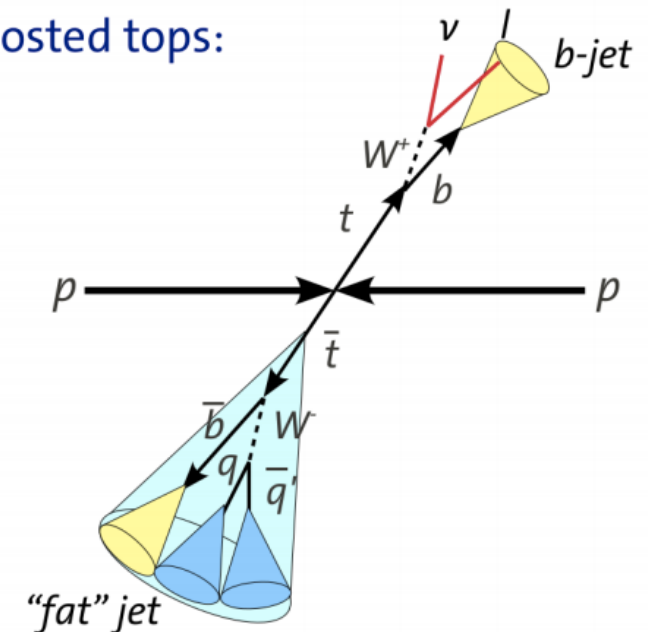
- ▶ A special type of 4th generation particle predicted by many models
- ▶ $B \rightarrow tW, bZ, bH$
- ▶ $T \rightarrow bW, tZ, tH$
 - ▶ **With high p_T T/B — heavy reliance on jet substructure techniques for reconstruction!**



▶ Top quark pair resonances

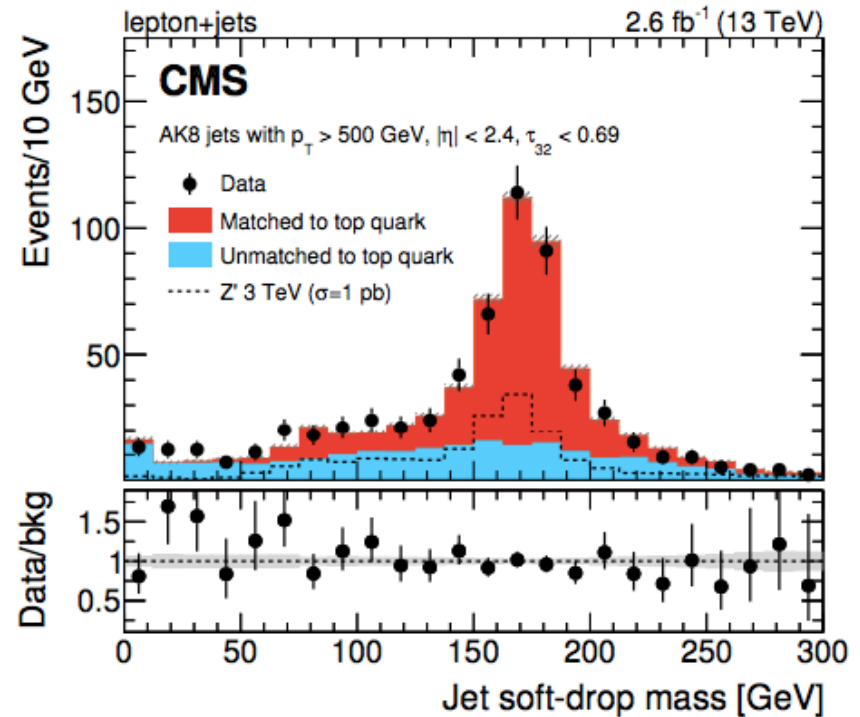
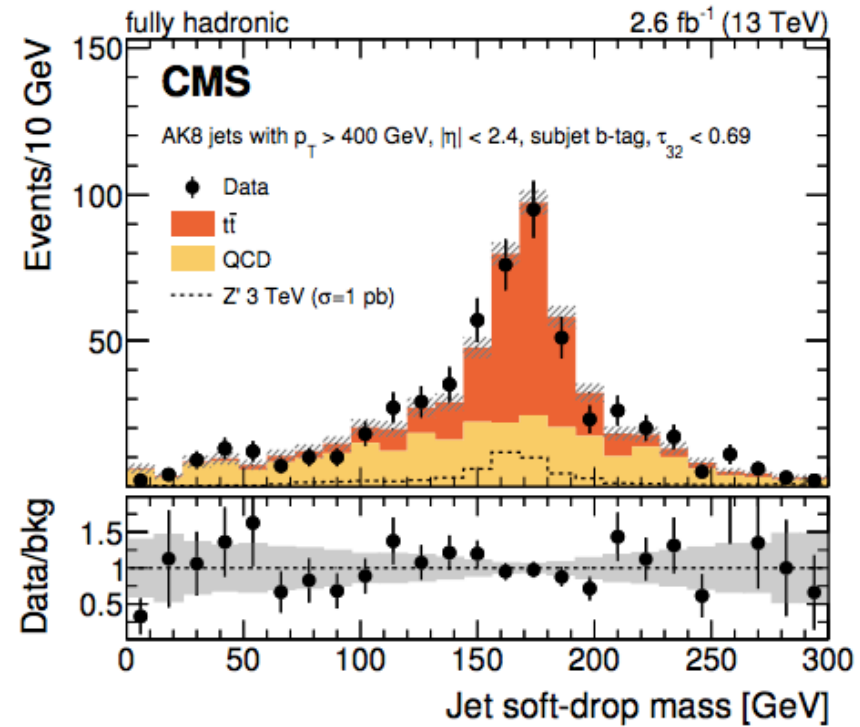
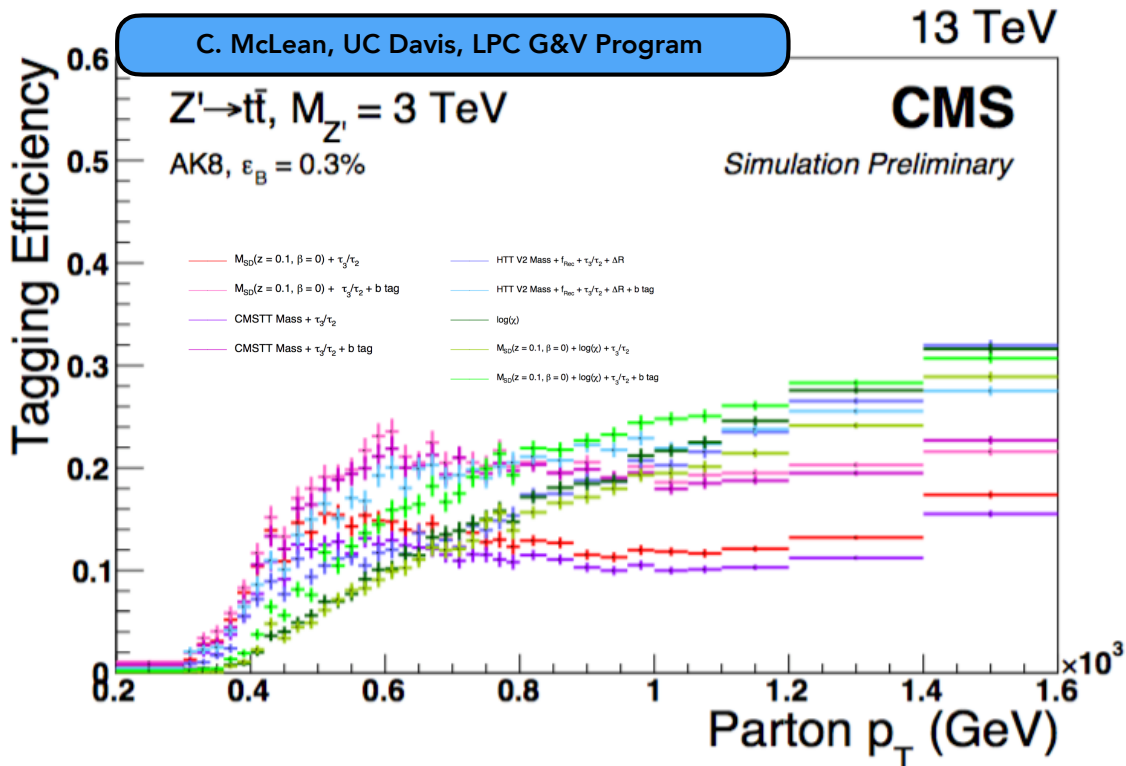
- ▶ Critically reliant on boosted top quark reconstruction to maintain efficiency to high-mass resonances
 - ▶ Hadronic top-tagging techniques
 - ▶ Non-isolated lepton reconstruction

Boosted tops:



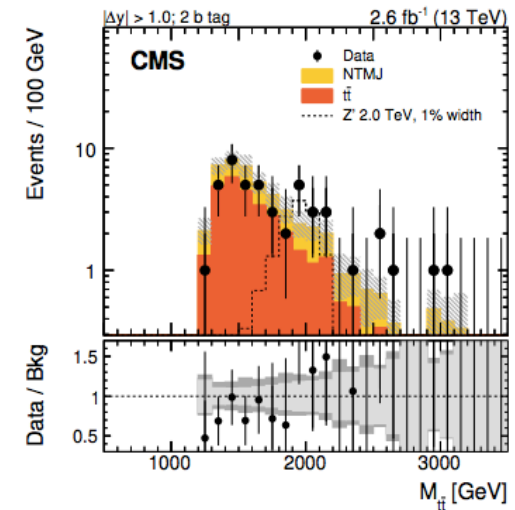
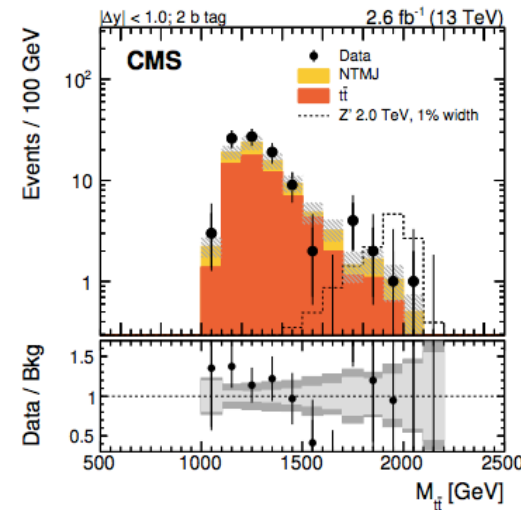
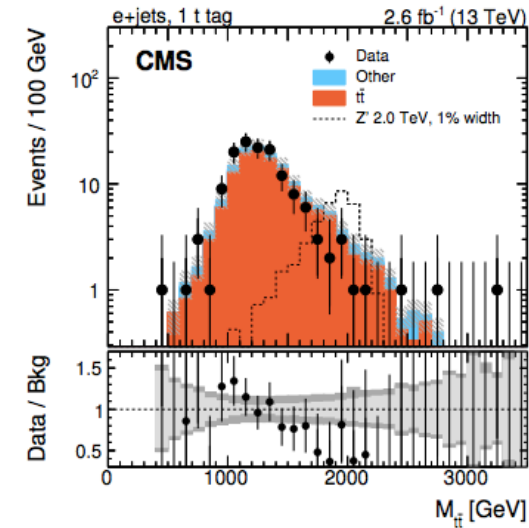
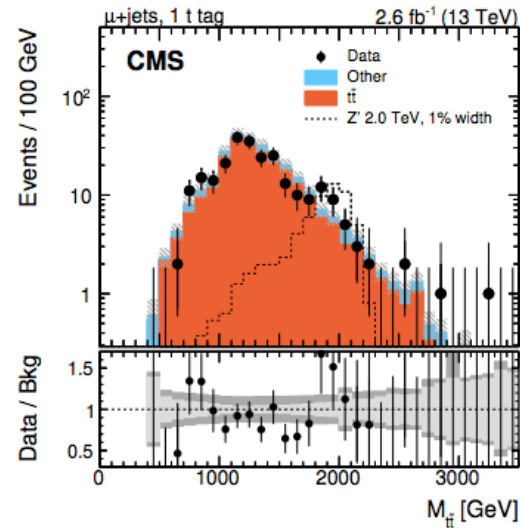
Top Pair Resonances

- ▶ An LPC collaboration!
 - ▶ All-hadronic channel — SUNY Buffalo, UC Davis, JHU, Hamburg
 - ▶ Lepton+jets channel — UIC, Hamburg
- ▶ For combination — important to coordinate on choice of analysis cuts, e.g. top-tagging variables



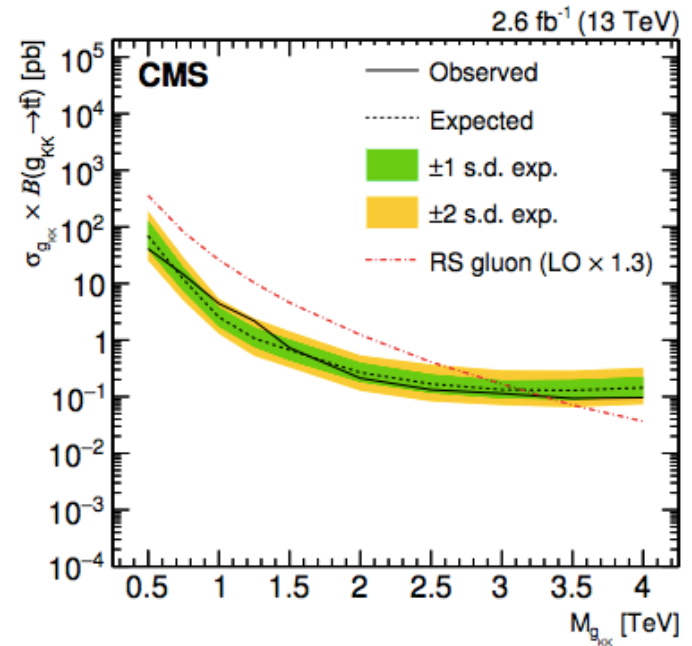
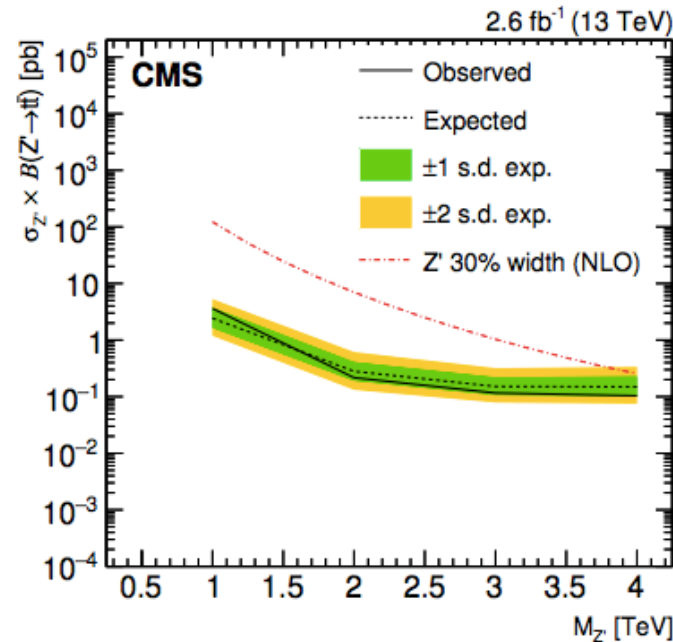
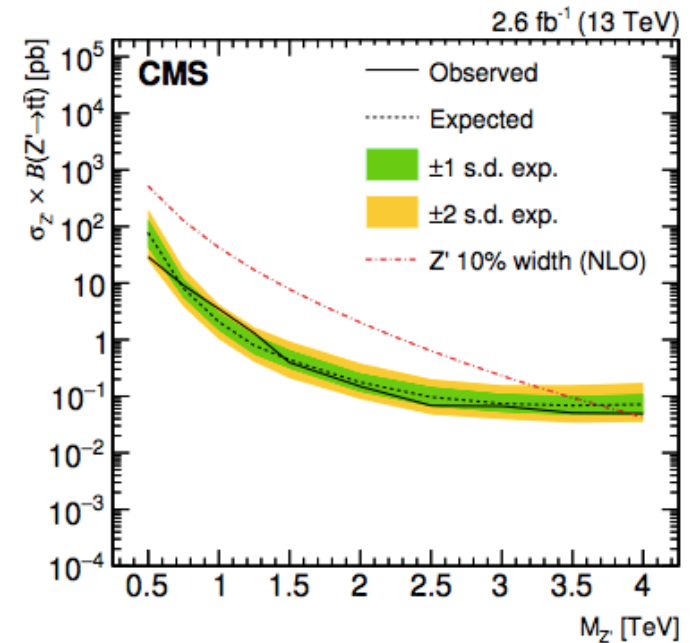
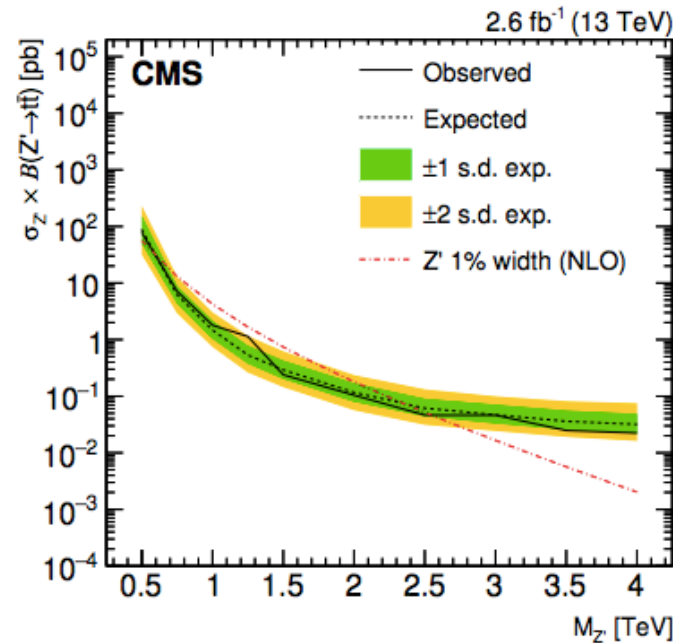
Combination Results

- ▶ Invariant mass of the candidate top quark pair is used for signal discrimination
 - ▶ Peak on falling background distribution
 - ▶ No sign of any new physics
- ▶ I was responsible for the combination of the all-hadronic and lepton+jets channels
 - ▶ Very useful to have (most) analysts here at LPC for quick communication about systematic correlation, binning, etc.



Combination Results

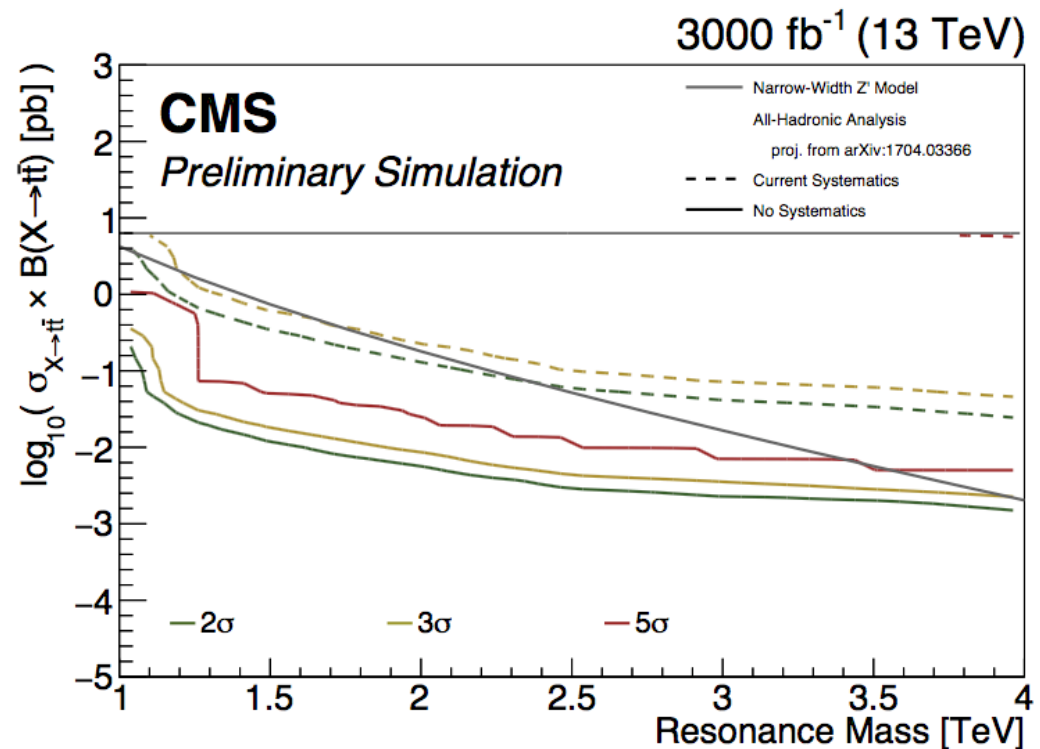
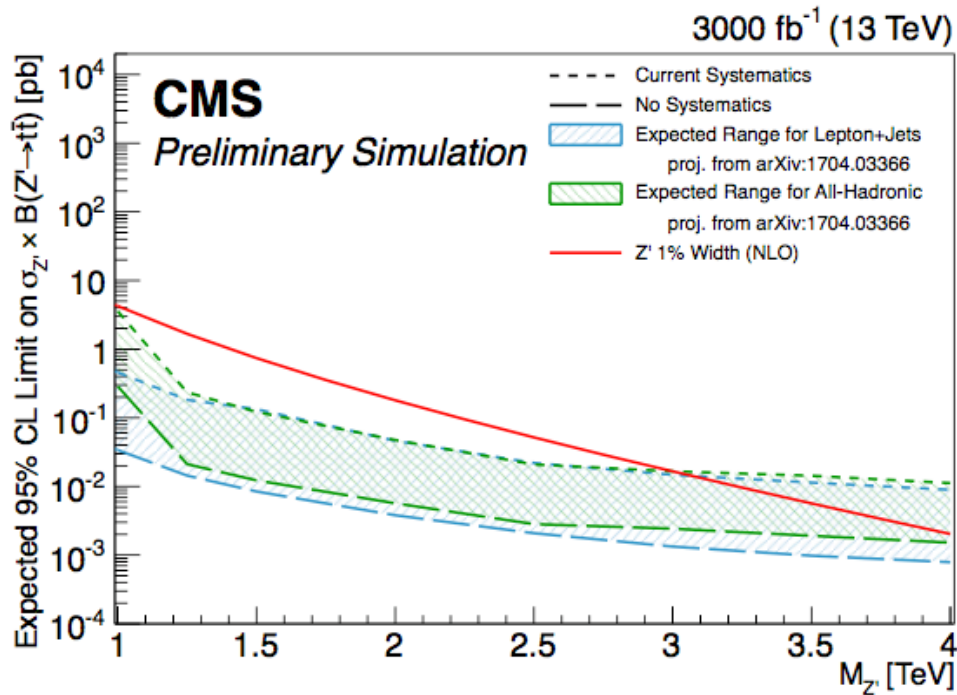
- ▶ We set limits on four physics models
 - ▶ Various widths
- ▶ Exclusion limits range from 2.5 to 4.0 TeV
- ▶ This is the first result with 13 TeV collisions
 - ▶ Published in JHEP 07 (2017) 001 on 3 July
- ▶ What about the future?!



ECFA Projections

- ▶ A group with leadership here at the LPC is studying physics reach for the HL-LHC (3000 fb^{-1})

- ▶ We projected the performance of this analysis to that future dataset
 - ▶ Problem — systematics limited!
 - ▶ Huge amount of data won't help us unless we can improve our analysis and understanding of backgrounds, e.g.



Working Hard for New Ideas!

- ▶ As part of my LPC DR proposal, we organized a workshop held here to focus on the future of jet substructure techniques
 - ▶ 52 participants from CMS, ATLAS and Theory!
- ▶ Many new ideas from the workshop are being tested in analysis frameworks



Jet Substructure "Planning for the future" Event at the Fermilab LPC

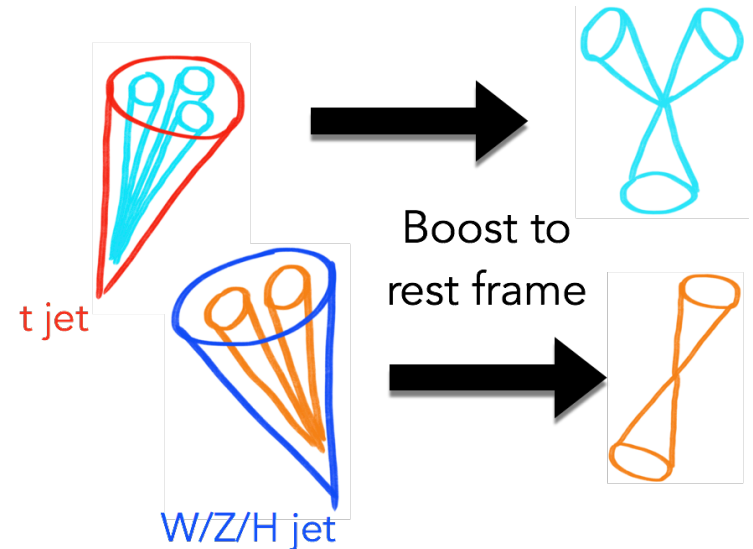
from 30 November 2016 to 1 December 2016
Fermilab LPC -WH8XO - Hornet's Nest
US/Central timezone

Search... 🔍

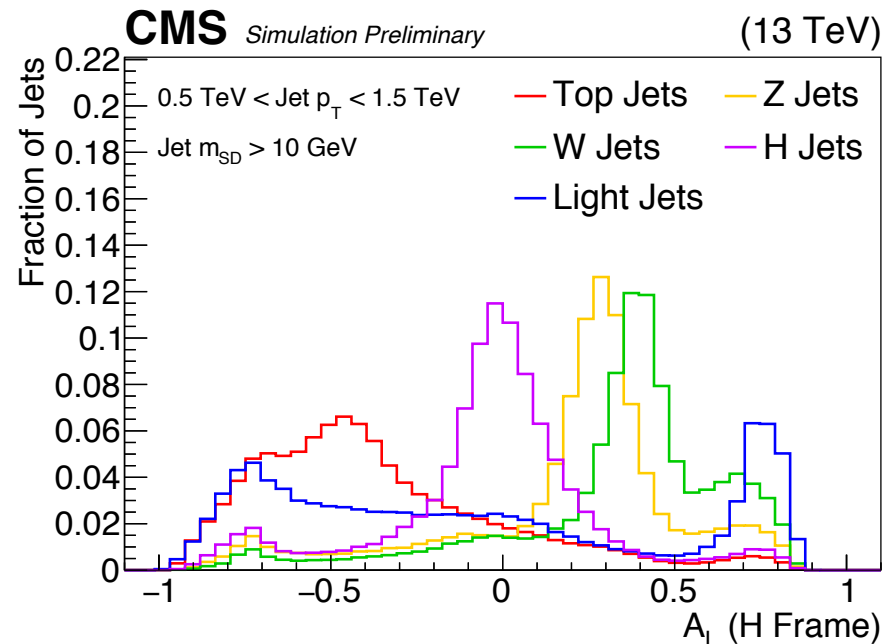
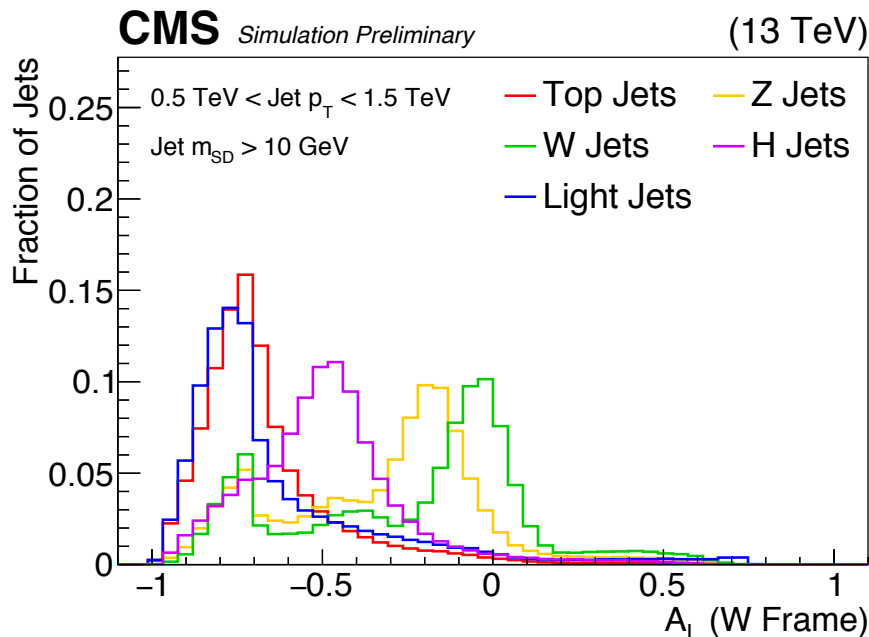
	Overview -- CMS Perspective	James William Dolen	
	Fermilab LPC -WH8XO - Hornet's Nest		09:10 - 09:35
	Overview -- ATLAS Perspective	Maximilian J Swatowski	
	Fermilab LPC -WH8XO - Hornet's Nest		09:35 - 10:00
10:00	Overview- Theory Perspective	Ian James Moutt et al.	
	Fermilab LPC -WH8XO - Hornet's Nest		10:00 - 10:25
	Coffee Break: Group Photo and Coffee Break		
	Fermilab LPC -WH8XO - Hornet's Nest		10:30 - 10:50
11:00	WIZ Tagging	Cristina Ana Mantilla Suarez	
	Fermilab LPC -WH8XO - Hornet's Nest		10:50 - 11:10
	Higgs Tagging	Caterina Vernieri	
	Fermilab LPC -WH8XO - Hornet's Nest		11:10 - 11:30
	Quark vs. Gluon Discrimination	Giorgia Rauco	
	Fermilab LPC -WH8XO - Hornet's Nest		11:30 - 11:50
	Top Tagging Algorithms	Christine Angela Mc Lean	
	Fermilab LPC -WH8XO - Hornet's Nest		15:00 - 15:20
	Coffee Break		
	Fermilab LPC -WH8XO - Hornet's Nest		15:20 - 15:40
	Jet Substructure in Heavy Ions	Raghav Kunnawalkam Elayavalli	
	Fermilab LPC -WH8XO - Hornet's Nest		15:40 - 16:00
	Energy Correlation Functions	Lina Necib	
	Fermilab LPC -WH8XO - Hornet's Nest		16:00 - 16:20
	Pileup Mitigation	Nhan Viet Tran	
	Fermilab LPC -WH8XO - Hornet's Nest		16:20 - 16:40
	Theory Wish-List	Andrew Larkoski	
17:00	Fermilab LPC -WH8XO - Hornet's Nest		16:40 - 17:10
	Discussion Time		8

Boosted Event Shape Tagger

- ▶ An algorithm to simultaneously classify hadronic decays of boosted heavy objects and discriminate them from the light-jet background
 - ▶ Target fully merged top quark, W, Z, and H boson jets
- ▶ Use hypothesized reference frames corresponding to each heavy particle mass
 - ▶ When boosting to 'correct' reference frame, jet constituents should be isotropic
- ▶ We compute several kinematic distributions in the different boosted reference frames and use these to train a neural network to perform the classification
 - ▶ Based on PRD 94 094027 (2016), first implementation in CMS shown at BOOST 2017

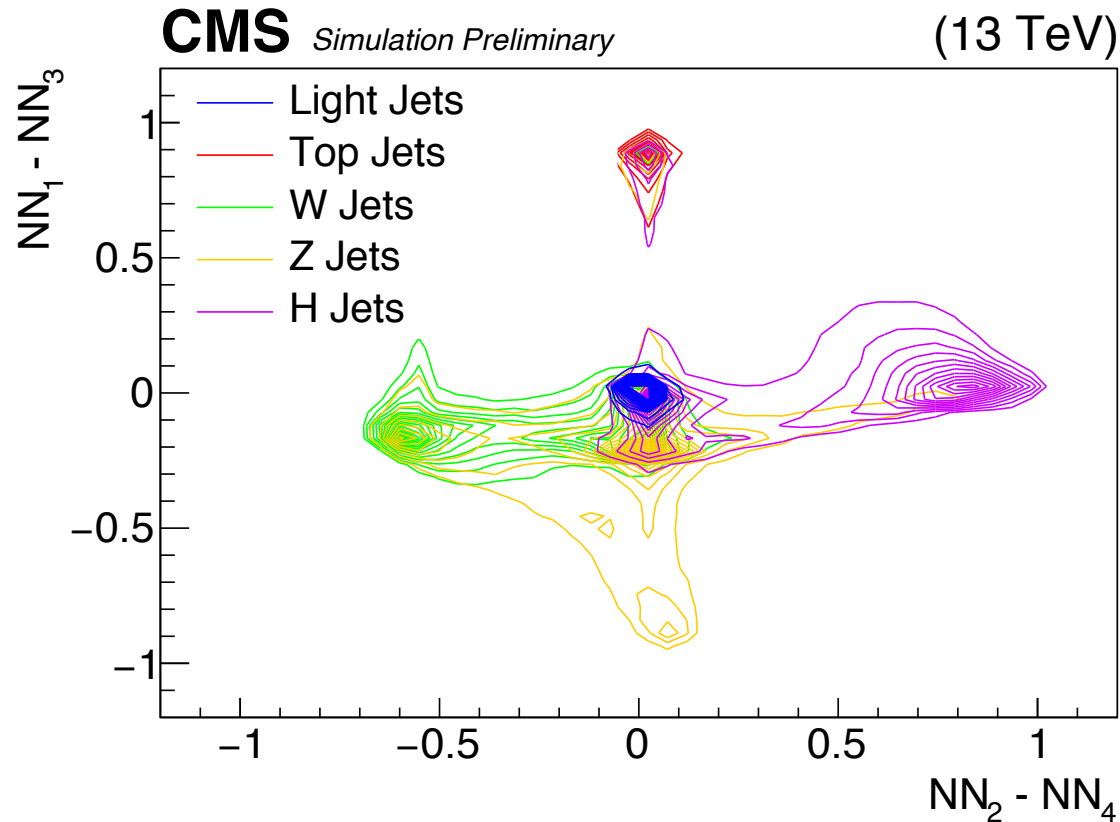


$$A_L = \frac{\sum p_z^{jet}}{\sum p^{jet}}$$



Boosted Event Shape Tagger

- ▶ Train a neural network to simultaneously separate the particle species
 - ▶ 41 kinematic quantities evaluated in the different boosted frames
 - ▶ 5 output values (each particle a unique target)
- ▶ Initial algorithm shows good performance
 - ▶ Best separation for top, Higgs jets
- ▶ Working further to gain performance, fully validate with data events and deploy in CMS analysis
 - ▶ Perfect application to vector-like quark search with high multiplicity final states



Pay it Forward

- ▶ Community of experts working hard to develop, validate, and implement new tools
- ▶ We also are responsible for the transfer of knowledge to newcomers joining the experiment
- ▶ I have served as an instructor for several CMS Data Analysis Schools
 - ▶ Leading students through an entire analysis; informing about latest algorithms



- ▶ Also worked to develop advanced HATS sessions to allow people to be able to work with the latest and greatest tools
- ▶ This is an important aspect of being a resident expert at the LPC!

Jet Algorithms and Substructure (Jets I) HATS@LPC

Wednesday 14 Jun 2017, 13:00 → 18:00 US/Central

Sunrise (WH11NE) (FNAL)

Alexx Perloff (Texas A & M University (US)) , Julie Hogan (Brown University (US)) , Justin Pilot (University of California Davis (US)) , Kevin Connor Nash (Rutgers, State Univ. of New Jersey (US)) , Marc Antoine Osherson (Rutgers, State Univ. of New Jersey (US))

Description: This hands-on tutorial will cover all aspects of jet reconstruction at CMS, including jet clustering and advanced jet substructure techniques. The tutorial will contain a broad overview of all CMS jet tools, including tools used to identify boosted heavy particles ($W/Z/H/top$), quark discrimination, and gluon jet identification. We will cover both the standard tools available in miniAOD and also more advanced tools.

CMS Data Analysis School

9 Jan 2017, 08:00 → 13 Jan 2017, 17:30 US/Central

Fermilab

Boaz Klima (Fermi National Accelerator Lab. (US)) , Cecilia Gerber (University of Illinois at Chicago (US))

Parallel Session Long Exercises: B2G Boosted Z' to $t\bar{t}$ semileptonic Hornets Nest (WH8XO) (F)

Conveners: Alexander Schmidt (University of Hamburg) , Justin Pilot (University of California Davis (US)) , Julie Hogan (Brown University (US)) , Julie Hogan (Brown University (US)) , Douglas Ryan Berry (University of Illinois at Chicago (US)) , Alexx Perloff (Texas A & M University (US))

08:00 Introduction talk for B2G Z' -> $t\bar{t}$ exercise 20m

Speaker: Justin Pilot (University of California Davis (US))

Conclusions

- ▶ **Jet substructure signatures are discovery signatures**
 - ▶ Will be critical to maintain analysis sensitivity as we push the searches for new physics higher and higher in energy
 - ▶ The community here at the LPC is on the leading edge of these developments, planning for an upcoming discovery!
- ▶ **The LPC at Fermilab has played an important role in my career to date on CMS**
 - ▶ Maintained strong analysis collaborations
 - ▶ Relied on expertise of others for understanding
 - ▶ Took part in educating the next rounds of students and new CMS members
- ▶ I have enjoyed my time at Fermilab and look forward to more exciting opportunities here at the LPC in the future!
- ▶ **Thank you to the DOE for your support of the program!**

