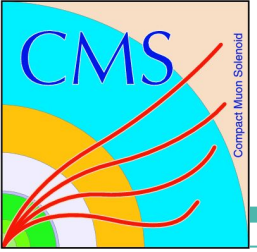

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DPF 2017

MEETING OF THE AMERICAN PHYSICAL SOCIETY DIVISION OF PARTICLES AND FIELDS

Search for a vector-like B quarks with oppositely-charged dilepton pairs in proton-proton collisions at 13 TeV

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DPF August 1, 2017

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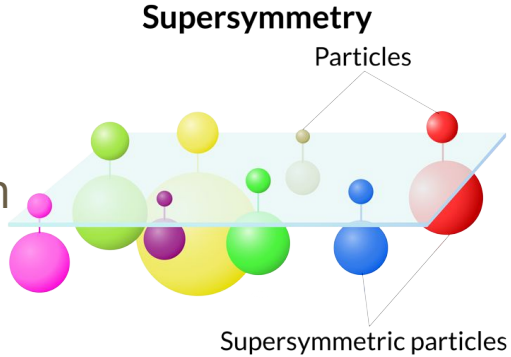
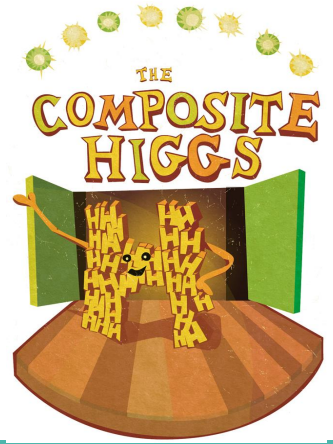
Vector-like Quarks

- Fermions similar to Standard Model quarks, but with some differences:
  - Left and right handed couplings
  - Gain mass through a direct mass term
  - Multiple particles and multiplets are possible
- Capable of solving the naturalness problem by cancelling top quark loop corrections
- Appear in many models
  - Composite Higgs, Extra Dimensions, and SUSY
- Can be created via single-production (EWK) or pair-production (QCD)
- Mix with Standard Model quarks
  - We assume the majority of mixing is with the third generations quarks for this analysis

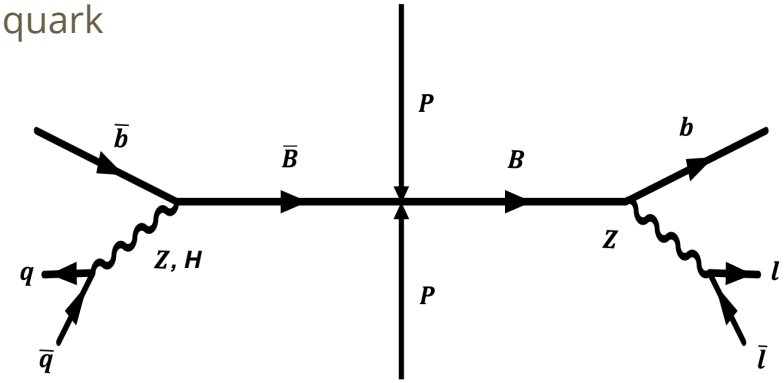




[1] https://www.sciencenews.org/sites/default/files/2016/09/090216_ec_supersymmetry_inline_free.jpg
[2] http://www.symmetrymagazine.org/sites/default/files/images/standard/DRAFT_higgs_composite_102212_AKG.jpg

Introduction

- Search for a massive bottom-like quark, B
  - This analysis focuses on FCNC decays of the B quark $B \to bZ$ and $B \to bH$
  - We only consider pair-production
- Final State:
  - Single opposite-sign dilepton pair from a Z boson decay
  - >= 3 AK4 jets [anti-kt, dR<0.4]
  - >= 1 b-tagged jet



- Pair-production signal cross sections are at NNLO
- Backgrounds are from simulation with corrections from data
- Using data collected in 2016 with at least one lepton (35.9 fb^{-1})

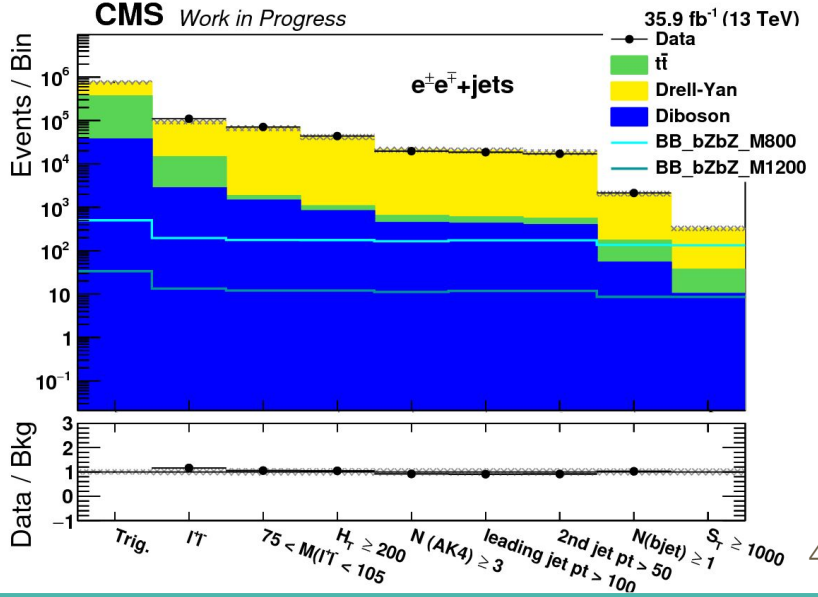
Event Selection and Dominant Backgrounds

- Preselection Region
  - 75 < M(Z) < 105 GeV
  - Exactly 1 dilepton pair
  - pT(Z) > 100 GeV
  - N (AK4) >= 3
  - HT > 200 GeV
- Signal Region
  - Leading (subleading) jet pT > 100 (50) GeV
  - N (bjets) >= 1
  - ST > 1000 GeV
- Control Regions
  - ST < 700 GeV **OR** N (bjets) == 0

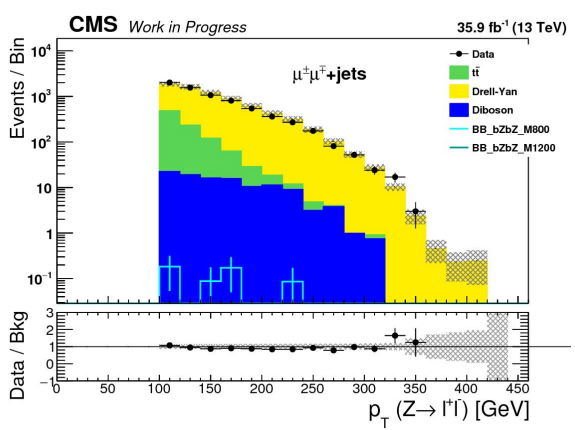
$$H_T \equiv \sum_{jets} P_T$$

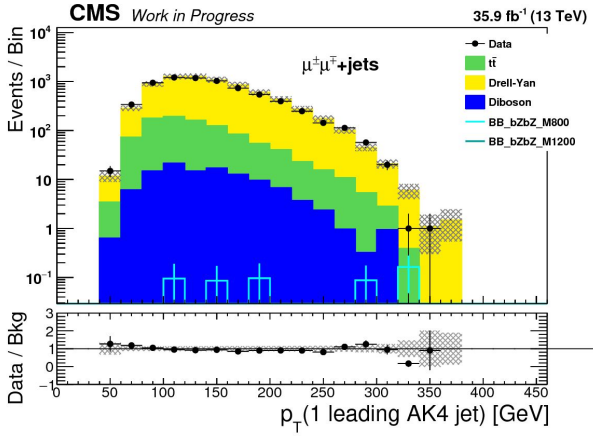
$$S_T \equiv \sum_{jets+leptons+MET} P_T$$

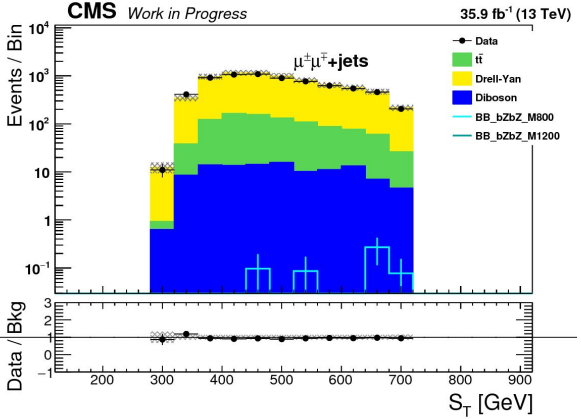
- Dominant Backgrounds
  - Drell-Yan
  - ttbar
  - Diboson

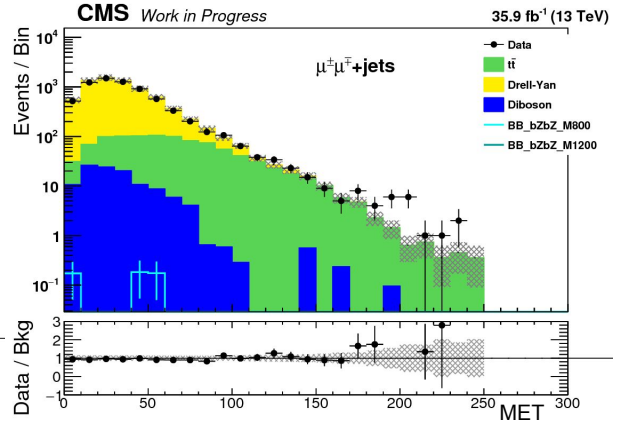


Control Region









Control region shows good agreement between data and MC

Search Strategy

- The most likely mass of the B quark will be reconstructed based on the minimization of a chi-squared function
- Events are split into two categories: boosted and resolved
  - Boosted - first choice; event has at least one Z/Higgs-tagged jet [AK8 jet using jet substructure techniques]
  - Resolved - no Z/Higgs-tagged jets, but at least 4 AK4 jets
    - Resolved category is further divided into two subcategories: single b-tag and multiple b-tag to increase sensitivity
- Scan over B mass window minimizing chi-squared for all permutations of final state objects

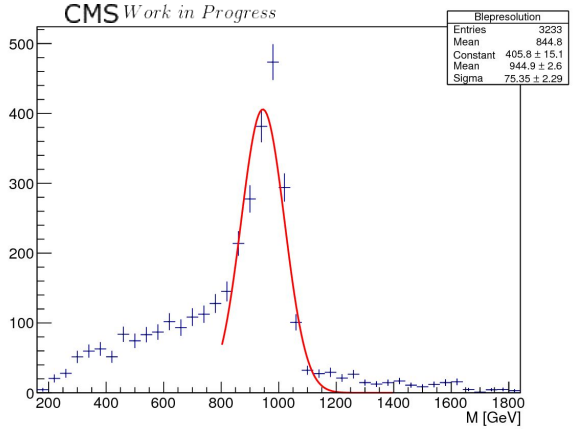
Chi-squared Resolution

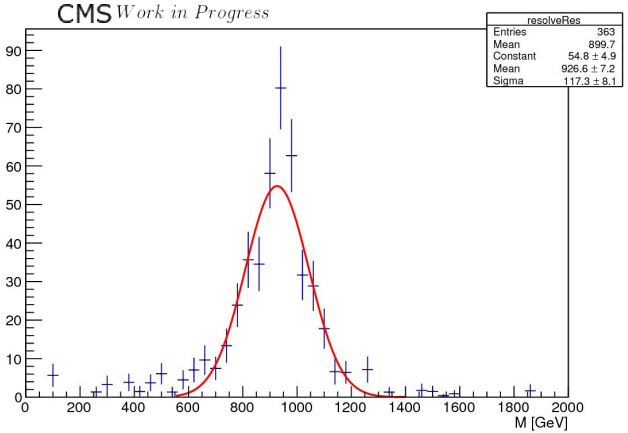
$$\chi^2_{res} = \frac{(m_{1,2} - m_{Z/H})^2}{\sigma^2_{Z/H}} + \frac{(m_{1,2,3} - m_B)^2}{\sigma^2_{B_{had}}} + \frac{(m_{4,l,l} - m_B)^2}{\sigma^2_{B_{lep}}}$$

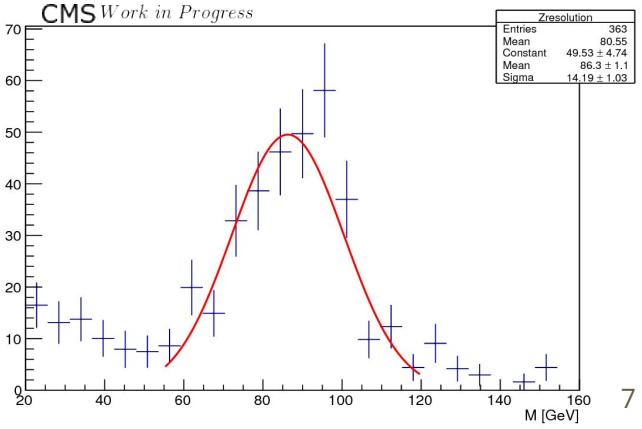
Resolution	GeV
$\sigma_{Z/H}$	14.19
$\sigma_{B_{had}}$	117.30
$\sigma_{B_{lep}}$	73.55

Resolutions for the chi-squared function are found by fitting a Gaussian to real Z bosons and B quarks

Other distributions were tested, but gave no real improvement in the final reconstruction





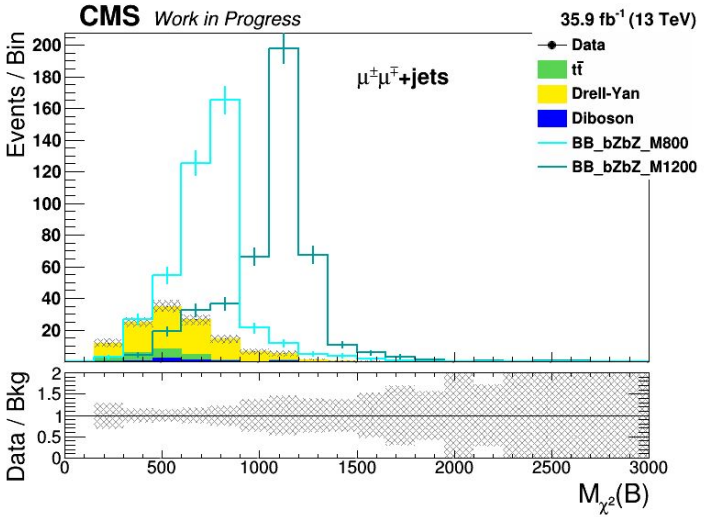


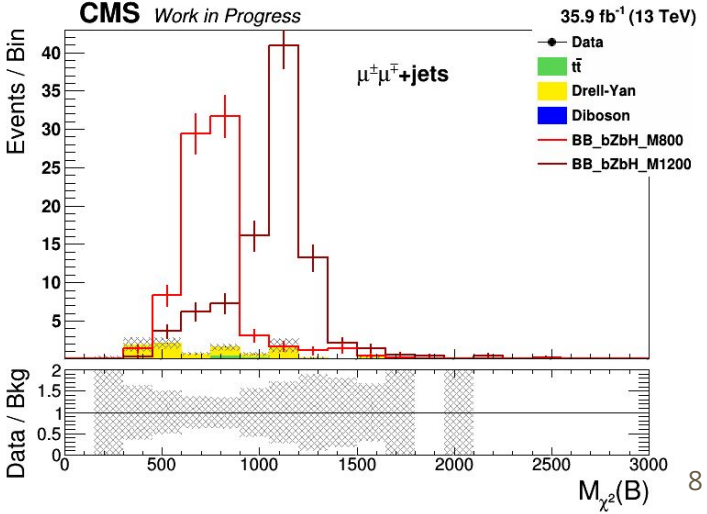
Boosted Reconstruction

$$\chi^2_{boost} = \frac{(m_{1'} - m_{Z/H})^2}{\sigma^2_{Z/H}} + \frac{(m_{1',1} - m_B)^2}{\sigma^2_{B_{had}}} + \frac{(m_{2,l,l} - m_B)^2}{\sigma^2_{B_{lep}}}$$

- Requires:
  - >= 1 Z-tagged AK8 jet
  - >= 2 AK4 jets
- Gives greater sensitivity than any other category

	Electron Events		Muon Events	
Sample	$B\bar{B} \to bZbZ$	$B\bar{B} \to bZbH$	$B\bar{B} \to bZbZ$	$B\bar{B} \to bZbH$
DY	52.57 ± 4.06	3.41 ± 0.78	103.25 ± 6.71	8.84 ± 1.54
Top	5.69 ± 2.05	0.27 ± 0.23	17.98 ± 1.93	0.91 ± 0.42
Diboson	3.55 ± 1.44	0.00 ± 0.00	5.67 ± 1.81	0.00 ± 0.00
$B\bar{B}$, M800 GeV	62.61 ± 2.41	9.73 ± 0.68	82.06 ± 2.74	15.43 ± 0.85
$B\bar{B}$, M1200 GeV	4.31 ± 0.15	0.90 ± 0.05	5.27 ± 0.17	1.10 ± 0.05
Total Bkg	62 ± 4.43	3.68 ± 0.81	126.90 ± 7.21	9.75 ± 1.59





Resolved Reconstruction

$$\chi^2_{res} = \frac{(m_{1,2}-m_{Z/H})^2}{\sigma^2_{Z/H}} + \frac{(m_{1,2,3}-m_B)^2}{\sigma^2_{B_{had}}} + \frac{(m_{4,l,l}-m_B)^2}{\sigma^2_{B_{lep}}}$$

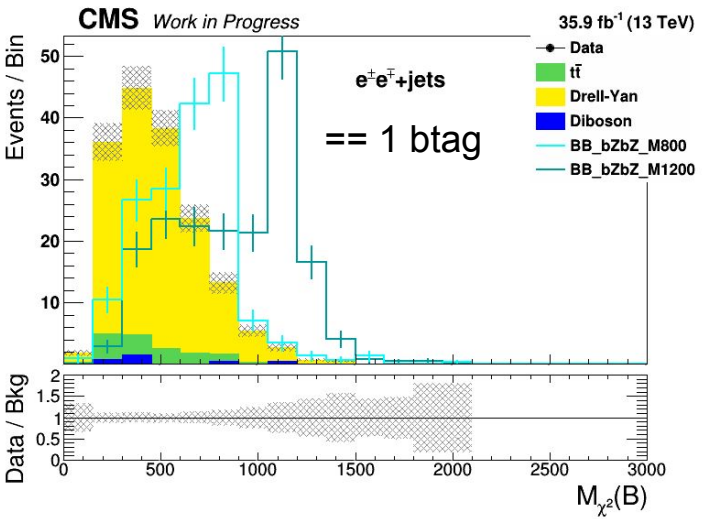
- Requires:
  - == 0 Z-tagged AK8 jet
  - >= 4 AK4 jets
- Resolved category is further split based upon b-tag multiplicity

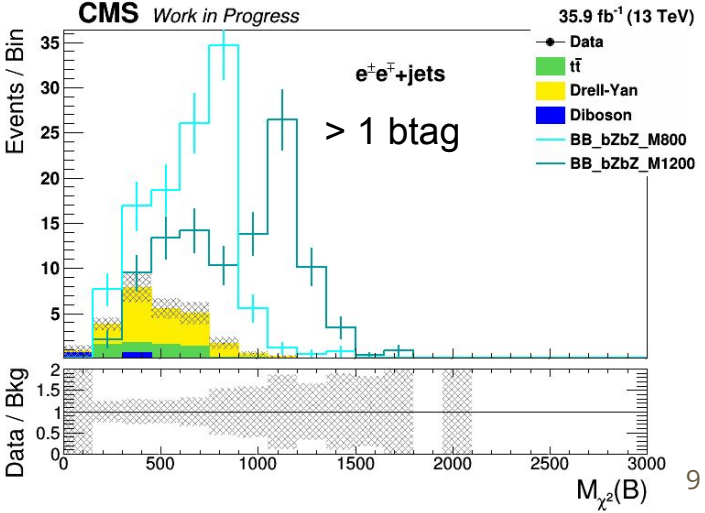
	Electron Events		Muon Events	
Sample	$B\bar{B} \to bZbZ$	$B\bar{B} \to bZbH$	$B\bar{B} \to bZbZ$	$B\bar{B} \to bZbH$
DY	150.64 ± 5.90	185.71 ± 6.77	330.73 ± 11.25	407.27 ± 12.76
Top	13.82 ± 1.63	17.16 ± 1.82	40.30 ± 2.78	50.14 ± 3.16
Diboson	3.48 ± 1.43	6.16 ± 1.90	4.07 ± 1.63	8.47 ± 2.29
$B\bar{B}$, M800 GeV	33.39 ± 1.65	26.99 ± 1.06	49.98 ± 2.01	36.44 ± 1.23
$B\bar{B}$, M1200 GeV	2.17 ± 0.10	1.96 ± 0.07	2.85 ± 0.12	2.36 ± 0.08
Total Bkg	167.94 ± 6.29	209.03 ± 7.26	375.10 ± 11.70	465.88 ± 13.34

Single b-tag Category

	Electron Events		Muon Events	
Sample	$B\bar{B} \to bZbZ$	$B\bar{B} \to bZbH$	$B\bar{B} \to bZbZ$	$B\bar{B} \to bZbH$
DY	18.30 ± 2.15	23.67 ± 2.59	48.07 ± 4.46	56.61 ± 4.77
Top	6.15 ± 1.09	7.99 ± 1.24	18.78 ± 1.90	23.73 ± 2.14
Diboson	1.33 ± 0.88	1.33 ± 0.88	0.00 ± 0.00	0.00 ± 0.00
$B\bar{B}$, M800 GeV	21.96 ± 1.34	32.59 ± 1.18	35.64 ± 1.71	49.82 ± 1.44
$B\bar{B}$, M1200 GeV	1.23 ± 0.08	2.06 ± 0.07	1.76 ± 0.09	2.57 ± 0.08
Total Bkg	25.78 ± 2.57	32.99 ± 3.01	66.85 ± 4.85	80.34 ± 5.23

Multiple b-tag Category





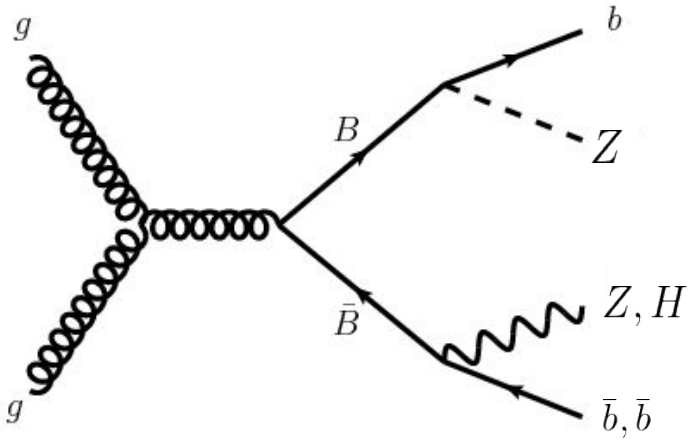
Conclusion

Presented a new search for vector-like B quarks in the opposite-sign dilepton channel

Work is still in progress and full unblinded results will be available later this year

Backup

Detailed Search Strategy



- For each event, the chi-squared function is evaluated at a hypothetical B mass for all permutations of jets in the event and the combination that gives the minimum value is kept
- Next, the hypothetical B mass is adjusted and the same minimization procedure is processed to get a new minimum value
- Finally, the minimum of minimum chi-squared values is found and the corresponding hypothetical B mass is taken as the most likely mass for that event