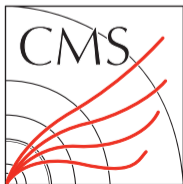# Toward a Measurement of the Z Boson Decaying to Four *b*-Quarks with the CMS Detector

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On Behalf of the CMS Collaboration

DPF-Pheno
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Motivation

- Goal: measure $b\bar{b}b\bar{b}$ branching fraction of Z boson at CMS
- Measured by LEP experiments to be $(3.6 \pm 1.3) * 10^{-4}$ (PDG average)
- Would be a high-precision test of QCD involving b-quarks
- Techniques could be applied to other SM/BSM resonances decaying to $b\bar{b}b\bar{b}$ i.e. $H \rightarrow AA \rightarrow b\bar{b}b\bar{b}$
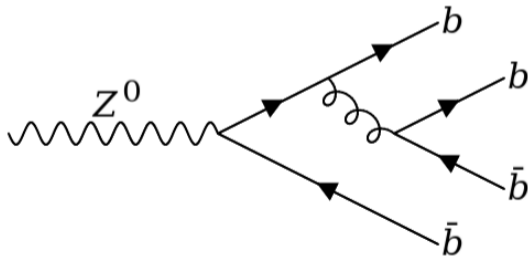
Approach

- LEP measured at Z mass, selected four jets with three b-tags
- At CMS, low boost requires additional boson to trigger on the event

Low Boost

Medium-High Boost

High Boost
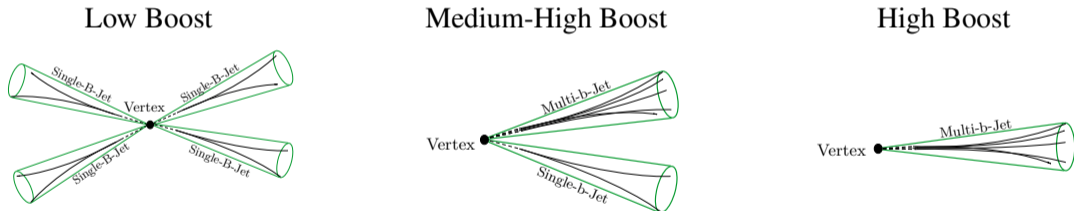
- For each, expect background events from QCD, $t\bar{t}$+Jets, $W^{\pm}$+Jets, Z^0+Jets (w/o $4b$)
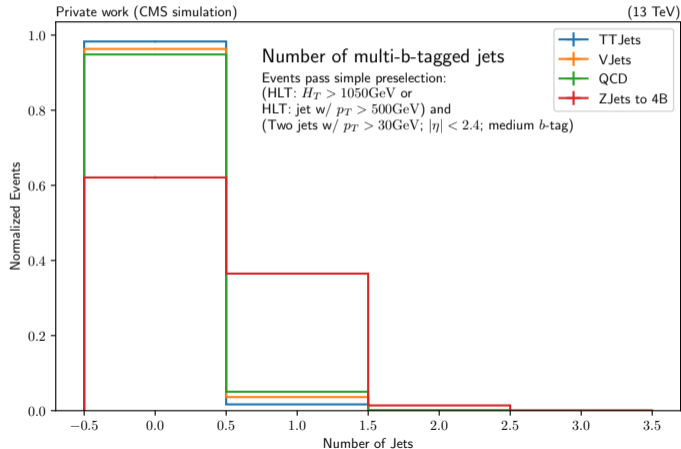
Approach

- CMS *b*-tagging includes information on both single-*b* and multi-*b* structures
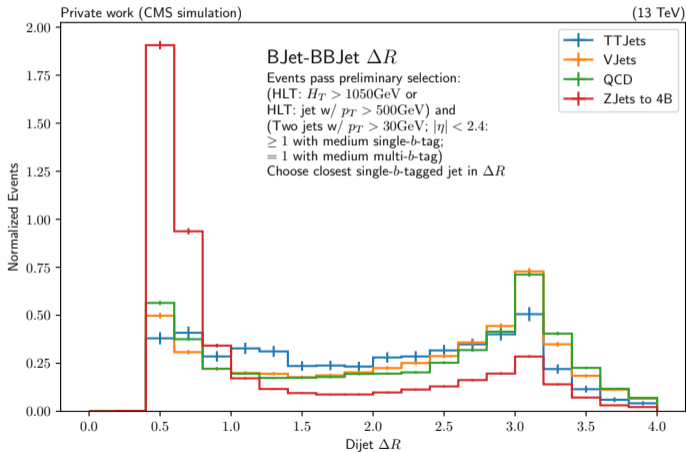- Single-*b*-tagged jets alone do not differ greatly between processes

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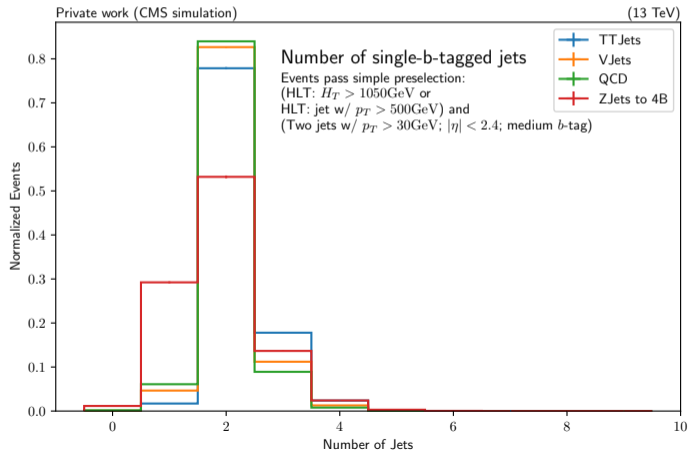
Approach

- Multi-*b*-tagged jets are powerful discriminant

- Target boosted Z^0 boson decaying to $b\bar{b}b\bar{b}$ in two jets
- Preselection:
  - ▶ HLT: scalar sum of jet $p_T > 1050$ GeV or single jet with $p_T > 500$ GeV
  - ▶ Two jets with $p_T > 30$ GeV, $|\eta| < 2.4$, medium b-tag
- At least two jets with $p_T > 30$ GeV, $|\eta| < 2.4$, and:
  - ▶ One passing medium multi-b-tag
  - ▶ At least one passing medium single-b-tag
- Build Z^0 system from multi-b-tagged jet and closest single-b-tagged jet in ΔR
- Require $\Delta R_{jj} < 1.5$
- Target $m_{jj} \in [70, 110]$ GeV

Dijet ΔR Cut

BJet-BBJet ΔR

Events pass preliminary selection:
(HLT: $H_T > 1050$GeV or
HLT: jet w/ $p_T > 500$GeV) and
(Two jets w/ $p_T > 30$GeV; $|\eta| < 2.4$:
≥ 1 with medium single-b-tag;
$= 1$ with medium multi-b-tag)
Choose closest single-b-tagged jet in ΔR

Private work (CMS simulation) — (13 TeV)

Legend: TTJets, VJets, QCD, ZJets to 4B

Dijet ΔR Cut

Private work (CMS simulation)   (13 TeV)

BJet-BBJet ΔR

Events pass preliminary selection:
(HLT: $H_T > 1050\,$GeV or
HLT: jet w/ $p_T > 500\,$GeV) and
(Two jets w/ $p_T > 30\,$GeV; $|\eta| < 2.4$:
≥ 1 with medium single-b-tag;
$= 1$ with medium multi-b-tag)
Choose closest single-b-tagged jet in ΔR

Legend:
- All Z to 4B
- Fully Tagged
- Mistagged

Y-axis: Events
X-axis: Dijet ΔR

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Data-Driven Background Estimation

- Backgrounds: QCD (largest), $t\bar{t}$+Jets, $W^{\pm}$+Jets, Z^0+Jets (w/o 4B)
- Can estimate backgrounds with ABCD method:
  - ▶ Create four bins A, B, C, and D from the combination of two independent boolean values
  - ▶ Reasonable to assume $\frac{A}{B} = \frac{C}{D}$ and estimate $A = \frac{BC}{D}$
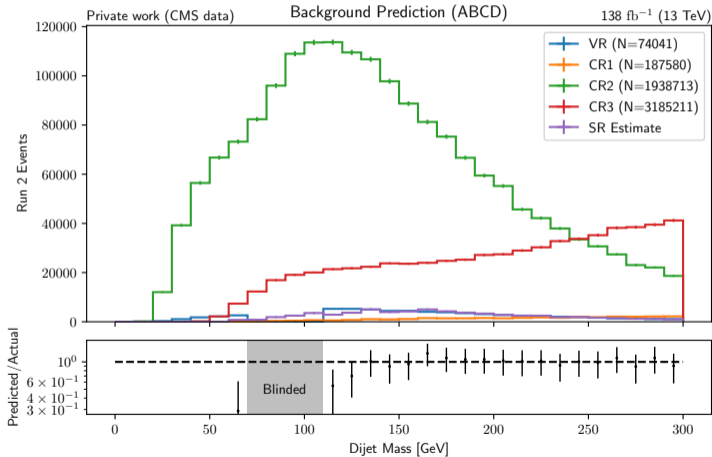- Define four regions, all passing preselection:

		Dijet ΔR	
		< 1.5	> 1.5
Jets b-tag	multi+ single	SR	CR1
	2x single	CR2	CR3

- When estimating background, only unblind "validation region" with $m_{jj} \notin [70, 110]$ GeV
- A few issues with this, but should be a reasonably close estimate for now
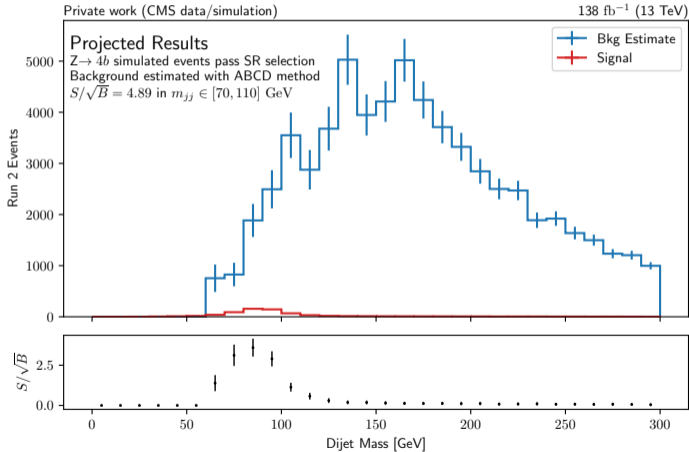
Background Estimate - Simulation
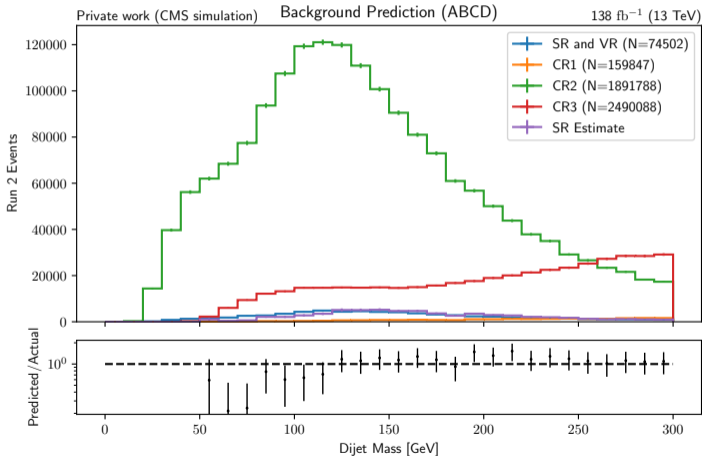
Background Estimate - Data

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Projected Sensitivity

Conclusions and Outlook

- Potential for $Z^0 \rightarrow 4b$ measurement at CMS explored using medium-high boost approach
- Preliminary projection looks promising with relatively simple analysis procedure
- Study ways to exploit multi-b-jet substructure
    - In ideal case expect exactly three b-quarks in jet
    - First ideas showed useful information exists but usage was not obvious
    - ML of some type may be best way to extract
- Explore additional approaches
    - Highly boosted case is interesting, but trouble distinguishing from boosted $Z^0 \rightarrow 2b$
- Improve background estimation
    - Current method is a good first step but likely underestimate in SR
- Expand to include Run 3