Probing low mass resonances with boosted jets

Boosted Dijet + ISR at 13 TeV search at CMS

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A new $Z'(qq)$ particle — low mass (50-300 GeV) — in a single jet.
Dijet searches:

- Collect (lots of) data with a trigger based on hadronic activity
- Select events based on jet properties
- Search for a bump over a smoothly falling dijet mass spectrum
Why no low mass constraints?

- Large QCD background
- Trigger thresholds due to limited storage capacity
Use ISR jet to get above trigger thresholds
Kinematic Selection:

- High $p_T$ (> 500 GeV)
- Trigger: high energy
  - HT 800 GeV

Backgrounds:

- QCD
- W/Z+Jets
- Top

ISR jet
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Substructure selection:
- Jet mass
- “2-prong”: $N^{DDT}_2$ > 0
  - 5% background efficiency
  - Preserves jet mass shape after selection
- Cutting on a variable \( (\text{independent on jet mass, } p_T) \) gives us another advantage:

\[
\rho = \ln\left(\frac{m_{SD}^2}{p_T^2}\right)
\]

- Data-driven QCD estimate: 
  \[
  \text{Pass}_{QCD} = \frac{\text{Pass}}{\text{Fail}} \times \text{Fail}_{QCD}
  \]

- Simultaneously fit pass and fail

FAIL: \( N_{2^{DDT}} > 0 \)

PASS: \( N_{2^{DDT}} < 0 \)
Events / 5 GeV

Data
Total SM pred.
Z(qq)+jets
Multijet pred.
single-t/t\bar{t}(qq)+jets
Z'(qq), g_{q'}=1/6, m_{Z'}=135 GeV

p_T: 800-900 GeV

7% σ unc.
First limits ever!

2.9 $\sigma$ local

First limits ever!
Summary

• Search extended to lower masses (below 100 GeV!)
  • EXO-17-001 ([arxiv:1710.00159](https://arxiv.org/abs/1710.00159))
• Novel background estimate and tagging techniques
• Program can be further extended:
  • Boosted Higgs(bb) search using same tagging and background estimate.
  • HIG-17-010 ([arxiv:1709.05543](https://arxiv.org/abs/1709.05543))
  • Probing gluon vs quark coupling
Questions?
Joe Pastika’s Slides

- Traditional $H \rightarrow bb$ search shows good agreement between SM and observations ($3.3\sigma$) at 13 TeV
- Dedicated search for events where boosted Higgs decay products end up in a single fat-jet
- Boosted channel significance of $1.5\sigma$

http://arxiv.org/abs/1709.07497
http://arxiv.org/abs/1709.05543
QCD Estimate

if MC correct:

R_{P/F} models Data/MC discrepancies:

Parametrize discrepancies with polynomial and fit to data.
Dark Matter constraints

\begin{itemize}
  \item \textbf{CMS} \\
      Vector mediator \\
      Dirac fermion DM \\
      $g_{\text{DM}} = 1.0$ \\
      $g_q = 0.25$ \\
\end{itemize}
Jet mass

Grooming removes soft and wide angle radiation

QCD jet

2-prong jet

CMS Preliminary

$X \rightarrow VH \rightarrow q\overline{q}bb$

35.9 fb$^{-1}$ (13 TeV)

Events / 5.0 GeV

H($b\bar{b}$), $m_x = 1200$ GeV
H($b\bar{b}$), $m_x = 4000$ GeV
W($q\bar{q}$), $m_W = 1200$ GeV
W($q\bar{q}$), $m_W = 4000$ GeV
Z($q\bar{q}$), $m_Z = 1200$ GeV
Z($q\bar{q}$), $m_Z = 4000$ GeV

B2G-17-002

soft drop jet mass (GeV)
Jet mass

QCD jet

Jet mass distribution for CMS Preliminary data with 2.3 fb$^{-1}$ at 13 TeV. The graph shows the normalized cross section as a function of groomed jet mass (GeV) for different p$_T$ bins.

Non-perturbative effects

The graph also includes a plot of events against the QCD scaling variable $\rho$, defined as $\rho = \ln(m_{SD}^2/p_T^2)$.

Use QCD scaling variable:
Jet $\rho = \ln(m_{SD}^2/p_T^2)$

We select: $-5.5 < \rho < -2$
e.g. for a 500 GeV p$_T$ bin: $30 < m_{SD} < 180$
Jet substructure: $N_2(1)$

QCD jet

2-prong jet

We make a selection with 5% background efficiency

Energy Correlation Functions: correlate particles inside jet

$$N_2(\beta) = \frac{2e_3^\beta}{(e_2^\beta)^2}$$
- Will sculpt mass distribution after selection
QCD jet

Decorrelate from jet mass and pT:

\[ N_2^{DDT} = N_2 - N_2(\varepsilon_{QCD}) \]

Each bin in pT and \( \rho \): 
\( N_2 \) 5\% quantile value
- NO sculpt mass distribution after selection
Jet substructure: $N_2(1)^{DDT}$

- Defines:

\[ \rho = \ln \left( \frac{m_{SD}^2}{p_T^2} \right) \]

$R_{P/F}$

"fail"

FAIL: $N_2^{DDT} > 0$

"pass"

PASS: $N_2^{DDT} < 0$