Combining Resonant and Tail-based Anomaly Detection

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Gerrit Bickendorf Manuel Drees Gregor Kasieczka Claudius Krause David Shih

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Bethe Center for Theoretical Physics Bonn

Outline

This talk: No new models, but new results.

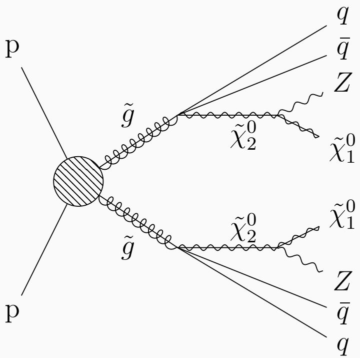
- Resonant anomaly detection and motivation
- Signal model and classical search
- Quick CATHODE recap
- Feature selection
- Results for nominal model
- Going beyond

Resonant anomaly detection and motivation

- Find feature where new physics is localised (inv. mass ...) $\rightarrow$ **S**ignal **R**egion
- Learn background template directly from data in additional features x
- Classify using difference between background template and data
  $\rightarrow R(x) = \frac{p_{\mathrm{data}}(x)}{p_{bg}(x)}$ "Anomaly score"
- Enhance significance by cutting on R
- So far: focused on localised features x e.g. τ_{ij} and global resonant feature e.g. dijet inv. mass
- Can be less strict:
  1. Can use any resonant feature as long as BG is smooth
     $\rightarrow$ Highly boosted Z,W,h .. common in decays of heavy particles
  2. Features x need not be localised
     $\rightarrow$ Anomalies on tails (e.g. p_T^{miss},H_T, M_{eff}) commonly found in TeV new physics

Let's test this generalised context on a supersymmetric scenario

Signal model



- RPC SUSY scenario
- Only active sparticles : $\widetilde{g}, \widetilde{\chi}_1^0, \widetilde{\chi}_2^0$
- $m_{\widetilde{g}} - m_{\widetilde{\chi}_2^0} = 50\mathrm{GeV}$
- $m_{\widetilde{\chi}_1^0} = 1\mathrm{GeV}$
- LSP $\widetilde{\chi}_1^0$ stable

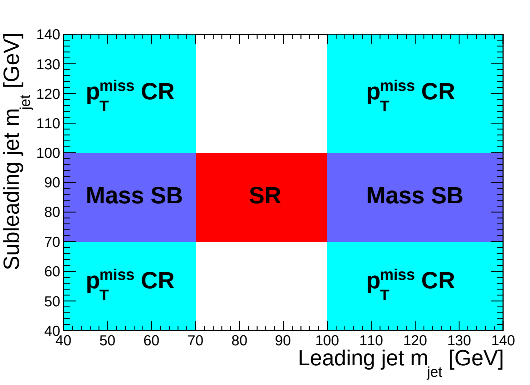
$\rightarrow$ Two highly boosted hadronic resonance at 91 GeV
$\rightarrow$ Large p_T^{miss} since $\widetilde{\chi}_1^0$ leaves detector
$\rightarrow$ Large H_T

Preselection

- $N_{\text{AK4 jet}} \geq 2$
- $p_T^{\text{miss}} > 300\ \mathrm{GeV}$
- $H_T > 400\ \mathrm{GeV}$
- at least 2 AK8 jets with $p_T > 200\ \mathrm{GeV}$
- $|\Delta\phi_j, \vec{H}_T^{\text{miss}}| > 0.5(0.3)$ for the first 2 (up to next 2) AK4 jets, where $\vec{H}_T^{\text{miss}} = -\sum_{\text{AK4 jets}} \vec{p}_T$
- no isolated photon, electron or muon candidate with $p_T > 10\ \mathrm{GeV}$
- no isolated track with $m_T < 100\ \mathrm{GeV}$ and $p_T > 5\ \mathrm{GeV}$ for tracks identified as an electron/muon or else 10 GeV.

Sirunyan et al. 2020.

Classical search strategy



- Funtional fit on leading jet m_{jet} in mass SB
  $\rightarrow$ normalisation
- p_T^{miss}-shape from p_T^{miss}-controlregion
  $\rightarrow$ shape
- Look for excess in binned p_T^{miss}-spectrum

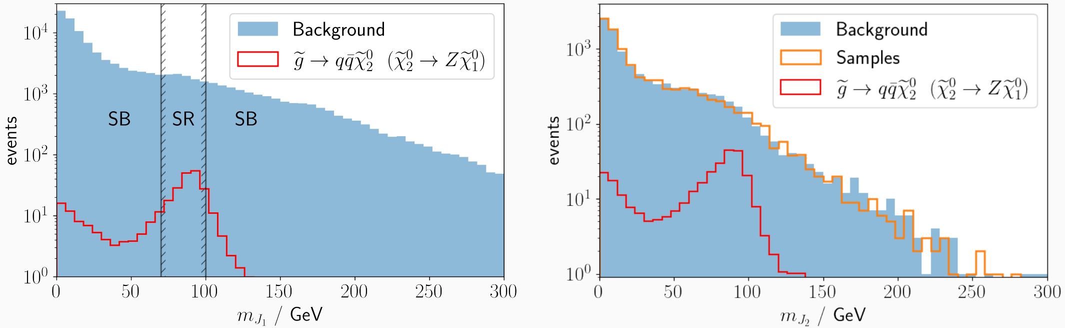
Sirunyan et al. 2020.

Quick intro to CATHODE

- Chose feature m where the signal is resonant and additional features x
  $\rightarrow m = m_{J1} \quad x = \left(m_{J2}, p_T^{\text{miss}}, H_T, \tau_{21}^{J1}, \tau_{21}^{J2}\right)$
- Train conditional desity estimator (MAF) on the sideband
- Interpolate to signal region
- Sample artificial samples (sample 40k, data 10k)
- Train classifier to classify between real data and samples: DNN with 3 layers à 64 nodes
- In practice: scan entire mass range to find the signal whereever its hiding

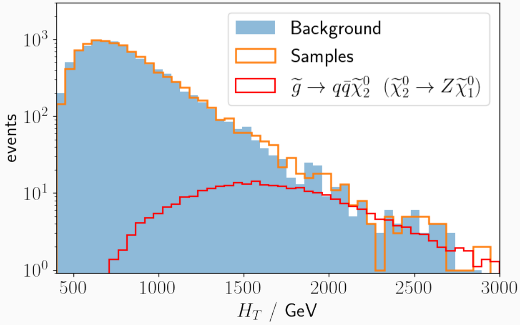
Hallin et al. 2022.

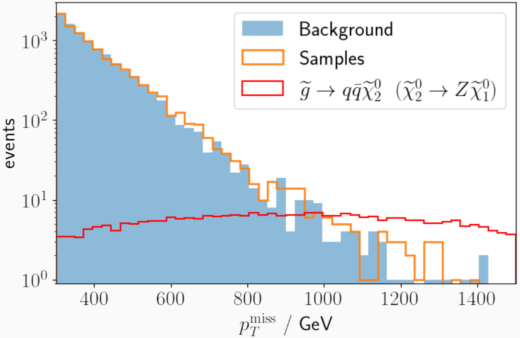
Distribution of features



- Chose SR in $m_{J1} \in \left[m\left(1 - \frac{4}{3}\sigma_m\right), m\left(1 + \frac{2}{3}\sigma_m\right)\right]$ with $\sigma_m = 15\%$
  $\to$ SR of classical search for boosted Z

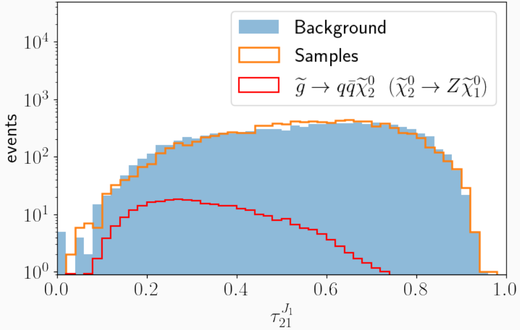
Distribution of features

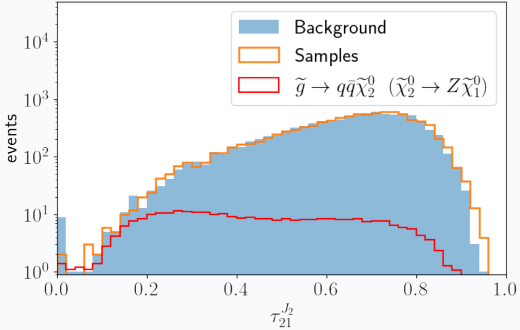




- Both H_T and p_T^{miss} are useful classification features
- Live on the tails

Distribution of features





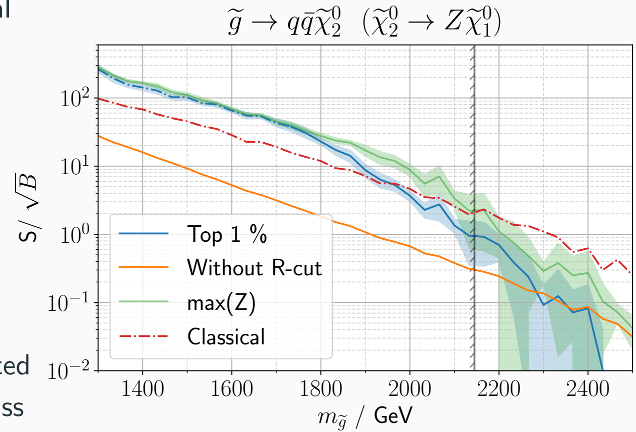
- Still useful: $S/\sqrt{B}$ from ~ 34 to ~ 40 for $m_{\tilde{g}} = 1700$ GeV

Results

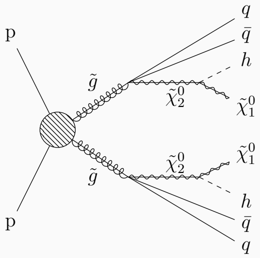
- Leave one out cross validation for DE and classifier
- Ensemble 4 x 10 DEs for sampling
- Assign avg. anomaly score of 10 classifiers
- Reshuffle 5x and repeat
- Repeat 10x with independent signal events
  $\rightarrow$ Expected sensitivity
- Fucus on $S/\sqrt{B}$ as a metric inplace of a proper statistical analysis

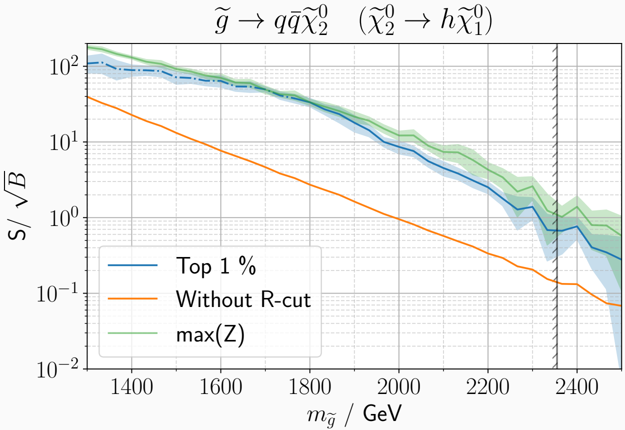
Z

- Cant directly compare classical (multibin) search with $S/\sqrt{B}$ $\rightarrow$ compare to $S/\sqrt{B}$ for $p_T^{\text{miss}} > 800\text{GeV}$ red
- Top 1% events sorted by anomaly score blue
- Maximise $S/\sqrt{B}$ with $B \geq 5$ green
- Vertical line: 300 fb^{-1} recreated expected 95%CL excluded mass
- 1% metric only slightly worse!



125 GeV Higgs

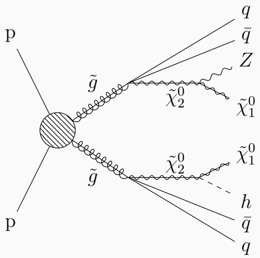




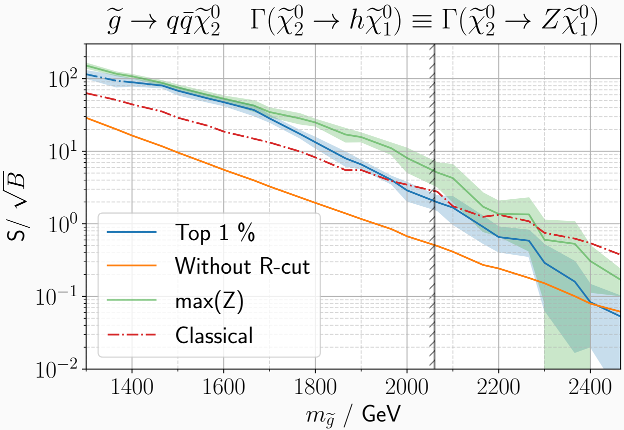
- No b-tag necessary

Tumasyan et al. 2022, @ 137/fb.

125 GeV Higgs and Z



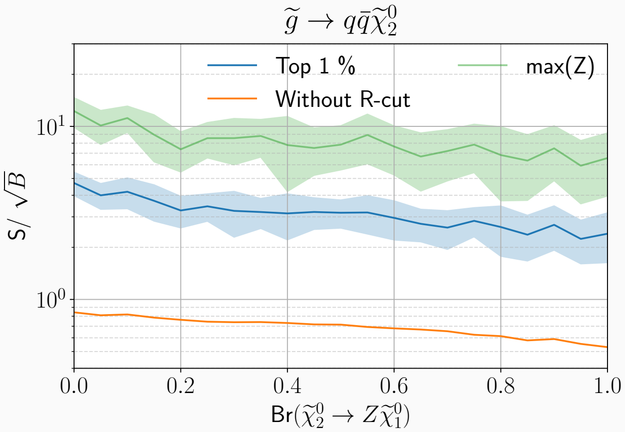
- $m_{J1} \in [70\ \mathrm{GeV}, 140\ \mathrm{GeV}]$



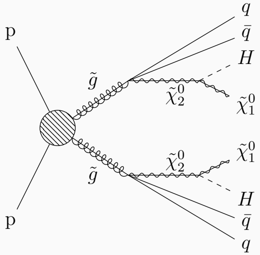
Sirunyan et al. 2018, @ 35.9/fb.

125 GeV Higgs and Z

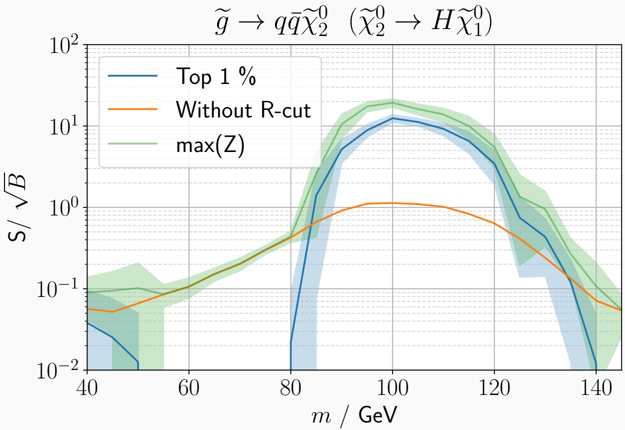
- $m_{\widetilde{g}} = 2000$ GeV
- Almost doesn't care about branching ratio



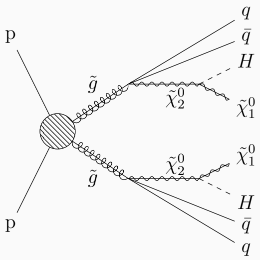
Additional Higgs

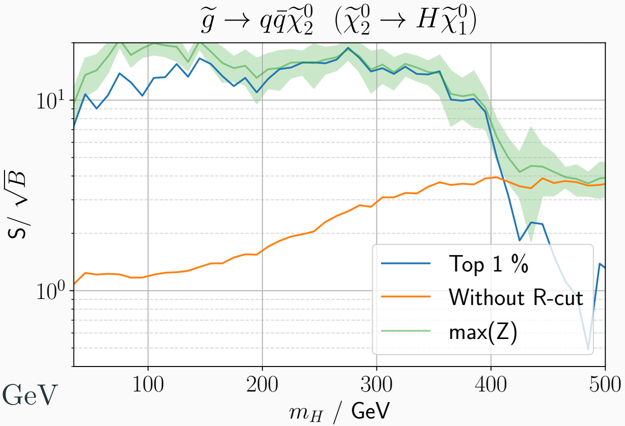


- $m_{\widetilde{g}} = 2000$ GeV
- $m_H = 100$ GeV



Additional Higgs





- $m_{\widetilde{g}} = 2000$ GeV
- Enhancement up to $m_H \sim 400$ GeV

Conclusion

- CATHODE works even for features on tails of distributions
- We don't lose much by going model agnostic compared to dedicated search
- Covers multiple signal models at once without extra work

References

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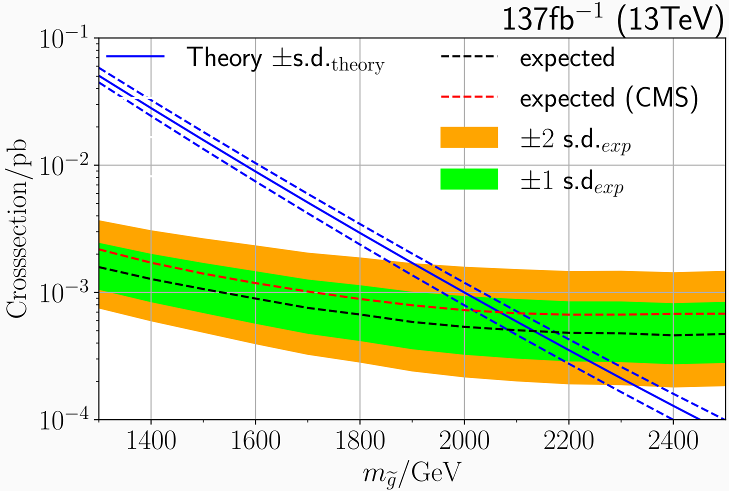
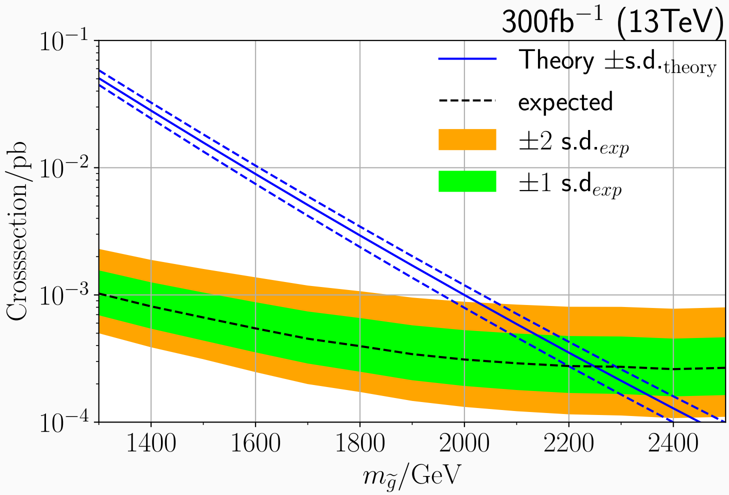
Backup

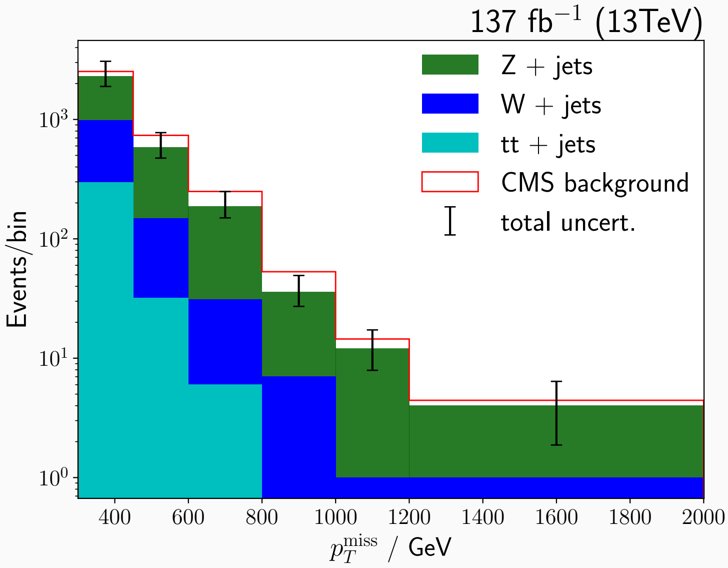
137 fb^{-1} recreation



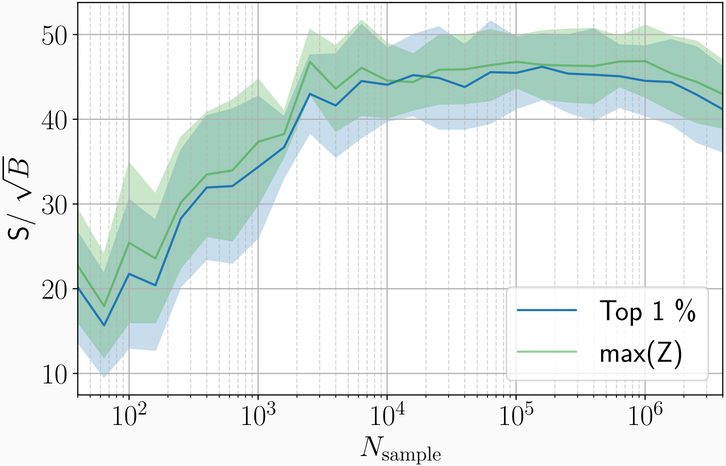
300 fb^{-1} recreation



p_T^{miss} spectrum classical search for 137 fb^{-1}



Oversample



50
40
30
20
10
$S/\sqrt{B}$
10^2
10^3
10^4
10^5
10^6
N_{sample}
Top 1 %
max(Z)