# Reinterpretation studies: search for VBS(ZZ) with the CMS experiment

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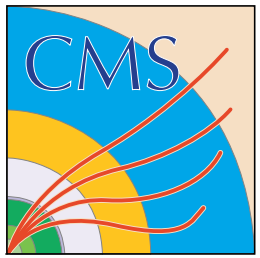



# Introduction

- Search for $VBS(ZZ)$ into $4l$, $2l2q$ and $2l2\nu$ final states using p-p collisions at $\sqrt{s} = 13\,TeV$.
- *CMS* detector data (2016) with $35.9 fb^{-1}$ integrated luminosity.
- Use of matrix element techniques.
- $VBS(ZZ)$ into $4l$ was already addressed in studies employing MVA/BDT.
  *Reference: Phys. Lett. B 774 (2017) 682*
- Matrix element techniques have already been used in a ZZ-high mass higgs studies, with the same three final states mentioned above.
- Reinterpretation of the methodology for $VBS(ZZ)$.

# Reference Study For Reinterpretation

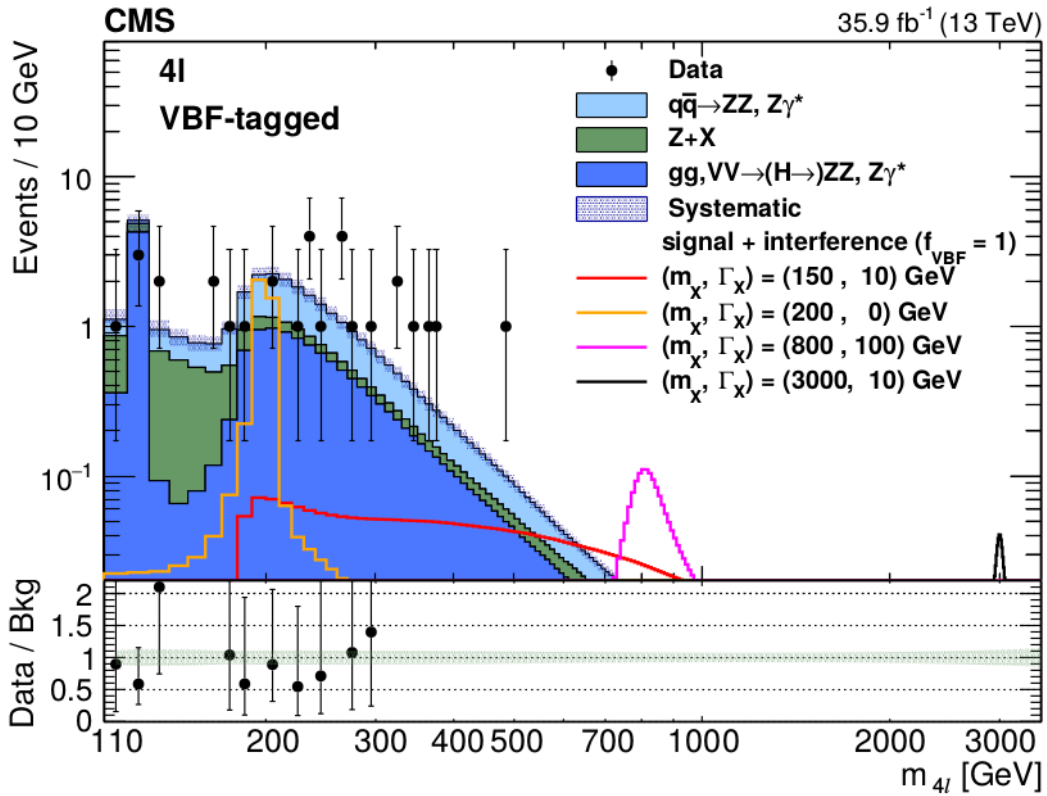
- "Search for a new scalar resonance decaying to a pair of Z bosons in proton-proton collisions at $\sqrt{s} = 13 TeV$" (arXiv:1804.01939)
- Study of a potential H(125) heavy scalar partner (X): $X \rightarrow ZZ \rightarrow 4f$
- Three possible final states: $4l$, $2l2q$ and $2l2\nu$

# Reference Study: Selection

- Mass ranges:
  - $4l$ final state $\rightarrow$ smallest background
    $\rightarrow$ cut at 130 GeV
  - $2l2\nu$ final state $\rightarrow$ large Z+jet background for low masses
    $\rightarrow$ cut at 300 GeV
  - $2l2q$ final state $\rightarrow$ large Z+jet background for low masses
    $\rightarrow$ cut at 550 GeV
- Other main cuts on $p_T$ and $\eta$ for leptons and jets.

# Reference Study: Mass Distributions I

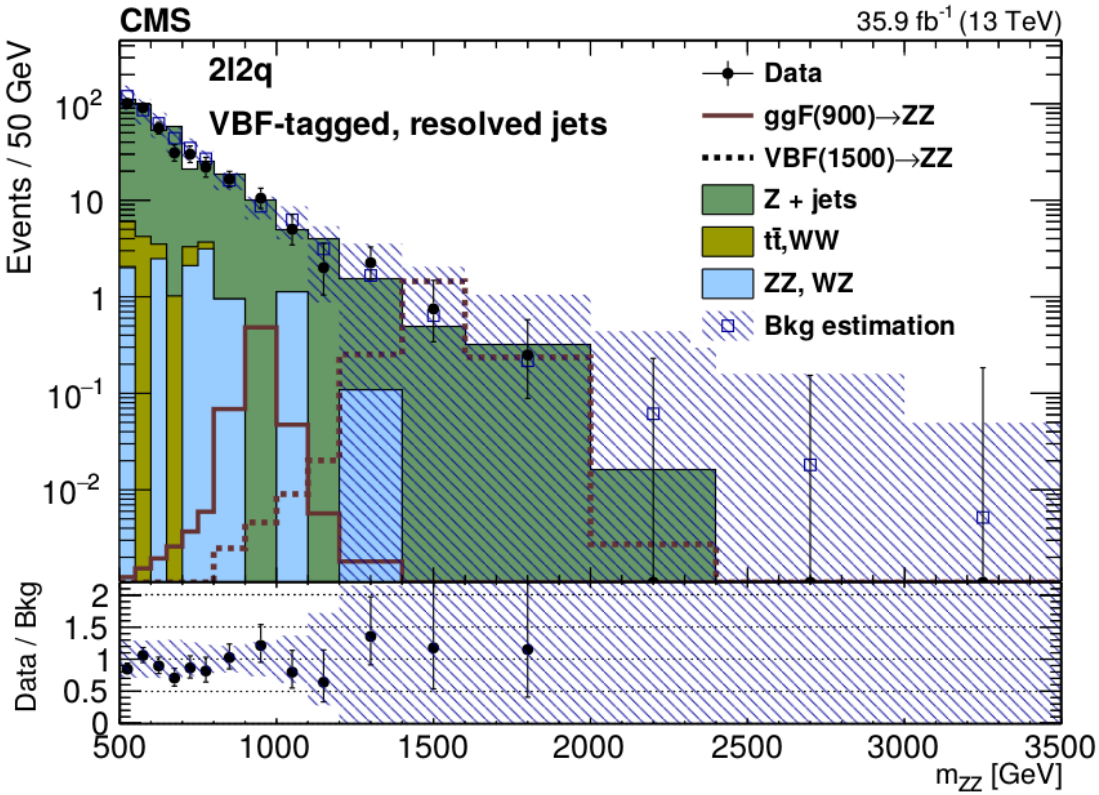
**arXiv:1804.01939**




*Distribution of the four-lepton invariant mass.*

# Reference Study: Mass Distributions II

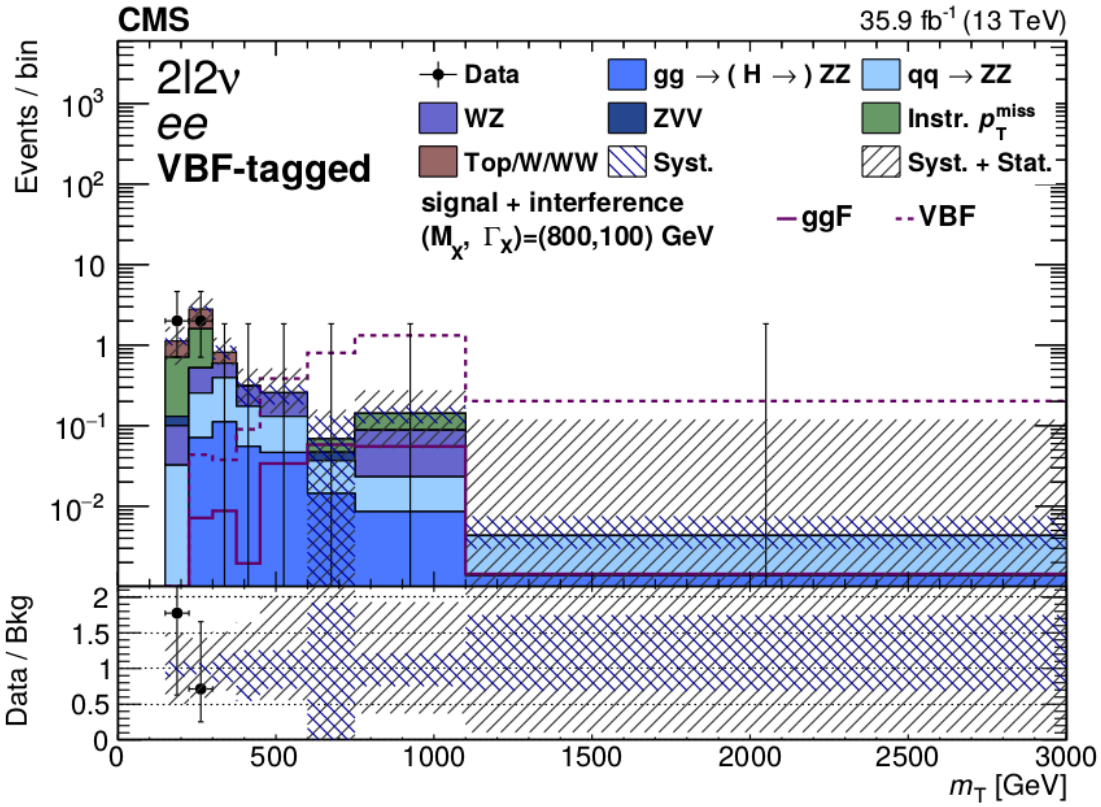
**arXiv:1804.01939**




*Distribution of the invariant mass $m_{ZZ}$ in the signal region.*

# Reference Study: Mass Distributions III

**arXiv:1804.01939**

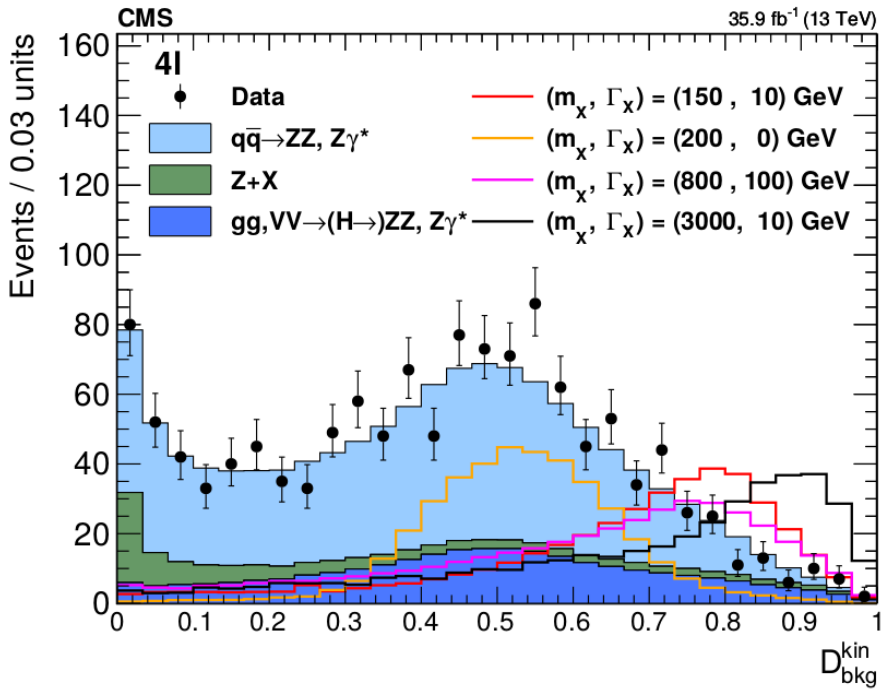



*Distribution of the transverse mass in the signal region for the 2e2$\nu$ channel.*

# Reference Study: MELA I

- Processes are studied at generator level, using JHUGen and MCFM matrix elements.
- Discriminants, based on matrix element calculations, are defined for categorizing events and separating signal over background.

**arXiv:1804.01939**

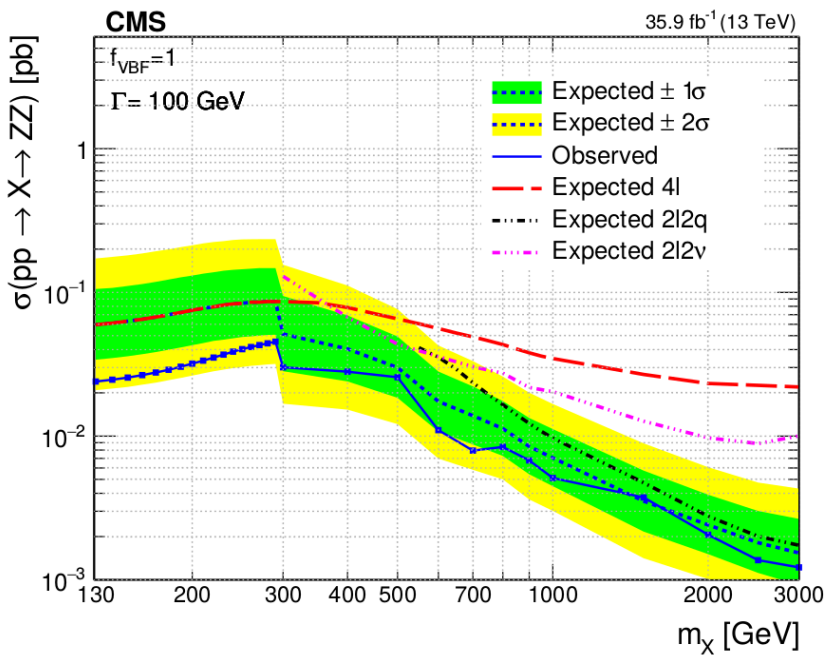



*Discriminant sensitive to $X \to ZZ \to 4l$ kinematic properties*

# Reference Study: MELA II

- 2D templates are created for mass and discriminant distributions.
- A profile likelihood analysis is performed using a statistical tool.
- The significance of signal over background and an upper limit on the cross section are computed.

**arXiv:1804.01939**



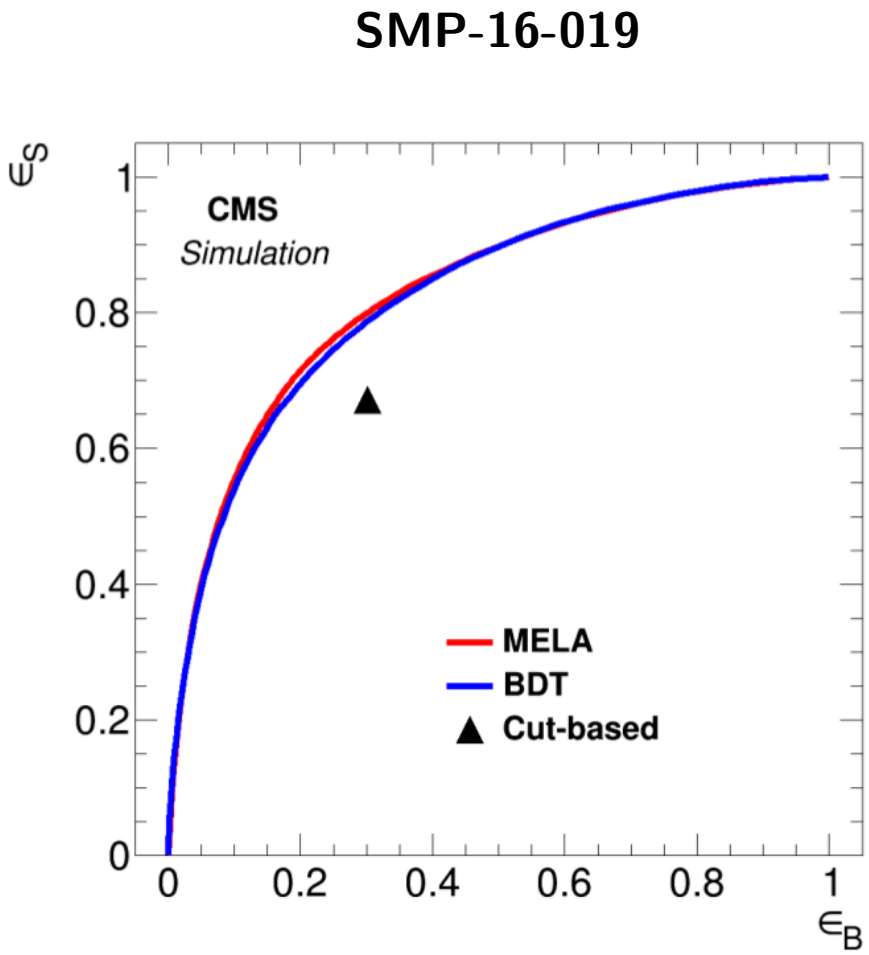

*Expected and observed upper limits at the 95% CL on the $X \to ZZ$ cross section as a function of $m_X$*

# Reinterpretation for VBS(ZZ)

- First focus on 4l channel $(4e, 4\mu, 2e2\mu)$
  $\rightarrow$ the other two channels will follow.
- Signal:
  - $VBS(ZZ)\ jj \rightarrow 4l\ jj$
- Background:
  - $gg \rightarrow ZZ/Z\gamma* \rightarrow 4l$
  - $q\bar{q} \rightarrow ZZ/Z\gamma* \rightarrow 4l$
  - single Z + jets
- Kinematic discriminant redefinition: $K_D = \frac{P_{VBS}}{P_{VBS}+const*P_{BKG}}$
- $P_{VBS}$ and $P_{BKG}$ are aggregated probabilities of several independent variables for a given 4l total mass.
- Significance is computed using the same statistical tool mentioned for the reference study.

# Mela vs. BDT

- In a previous study of $VBS(ZZ)\ jj \rightarrow 4l\ jj$, based on MELA, the ROC curve for both MELA and MVA/BDT was calculated. *Reference: "Studies of Gauge Couplings at LHC: the Effective Field Theory Approach", PhD thesis, Gomez-Ambrosio, Raquel.*
- MELA and BDT efficiencies result being comparable and both better than classic cut-based methods.



# Conclusions

- A new analysis of VBS(ZZ) processes is presented.
- The methodology of a previous ZZ-high mass study is reinterpreted for the new signal search.
- MELA will be employed instead of the more widely used MVA/BDT approach.