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# A collider search for Dark Matter produced in association with a Higgs boson in the four-lepton final state at the 13 TeV LHC with CMS

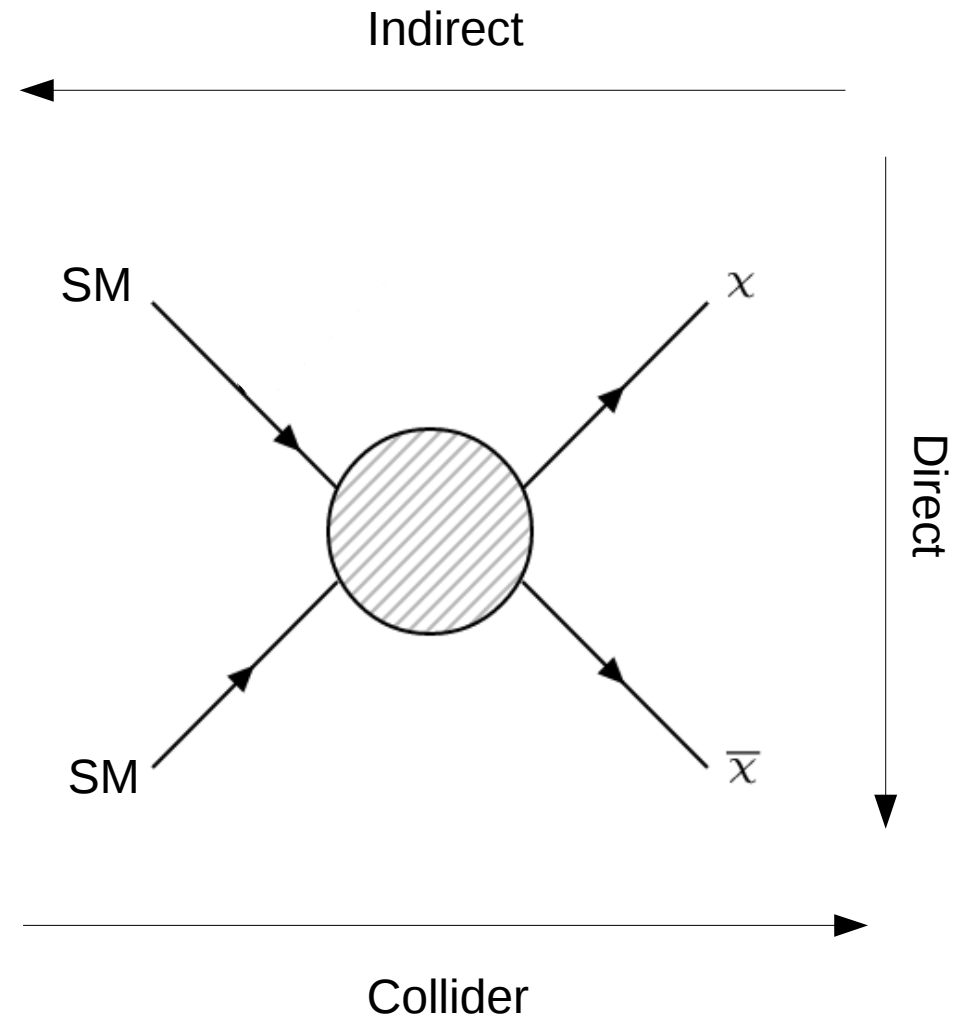
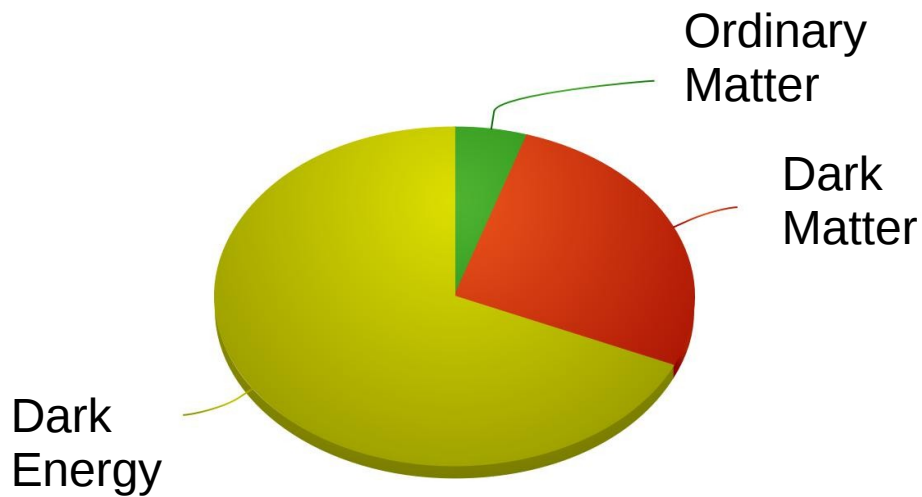
USLUA Annual Meeting: 2016

**Dustin Burns** - UC Davis  
on behalf of CMS

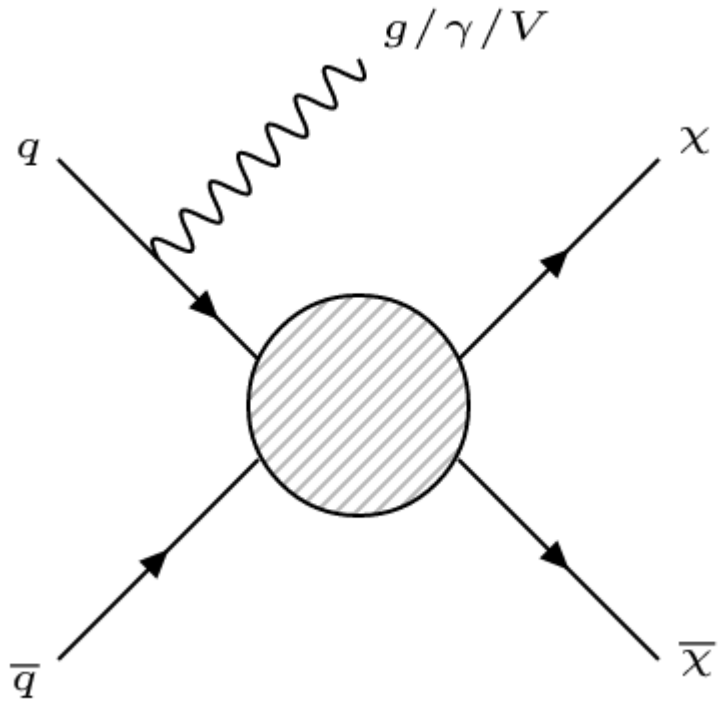


# Dark Matter Searches

Mass-Energy of the Universe

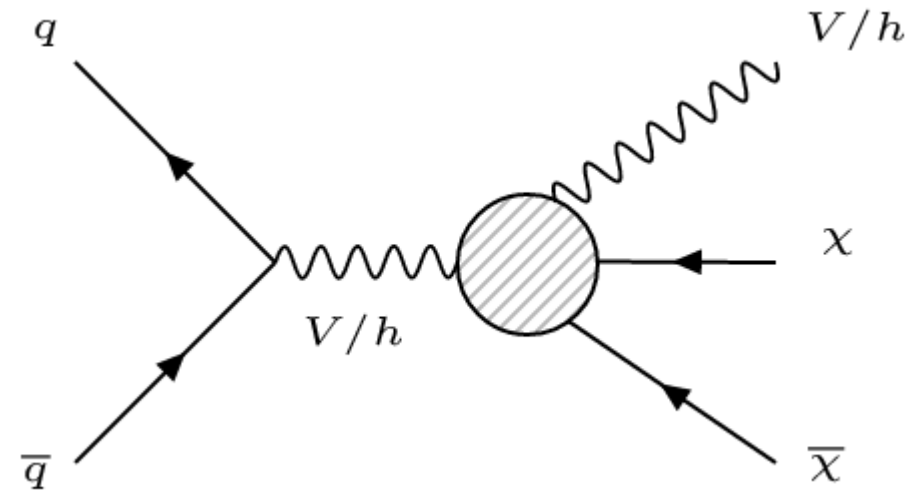


# Mono-Higgs Signature



Main approach to DM collider search:

- Combine mono-X channels from **ISR**

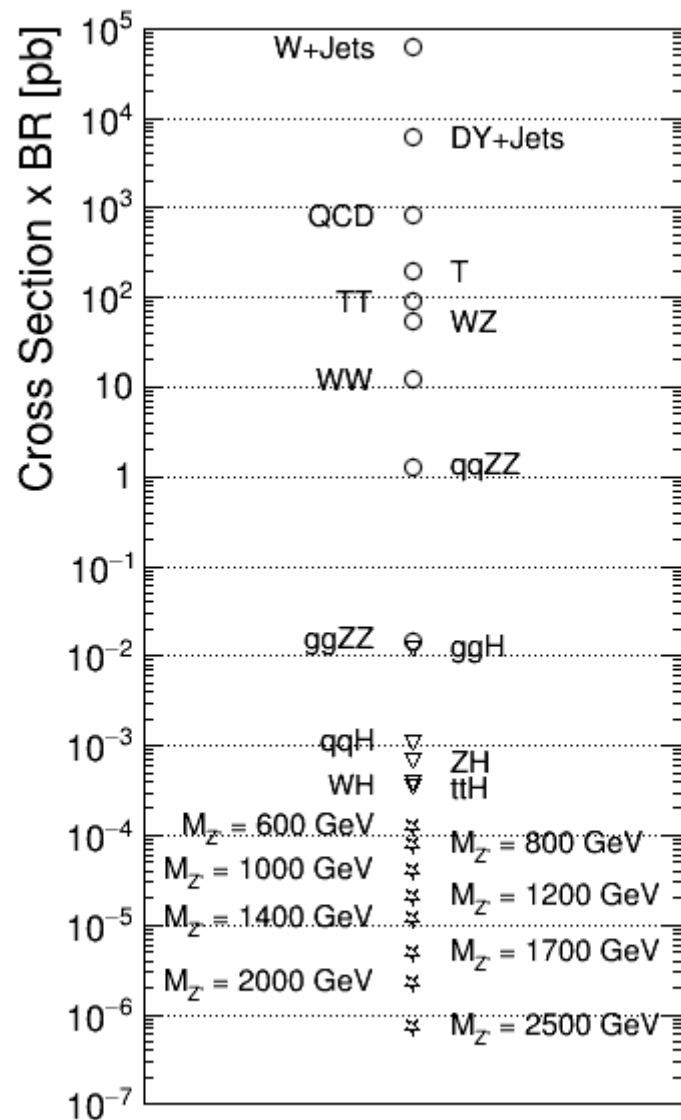


What if DM couples **ONLY** to  $X$ ?

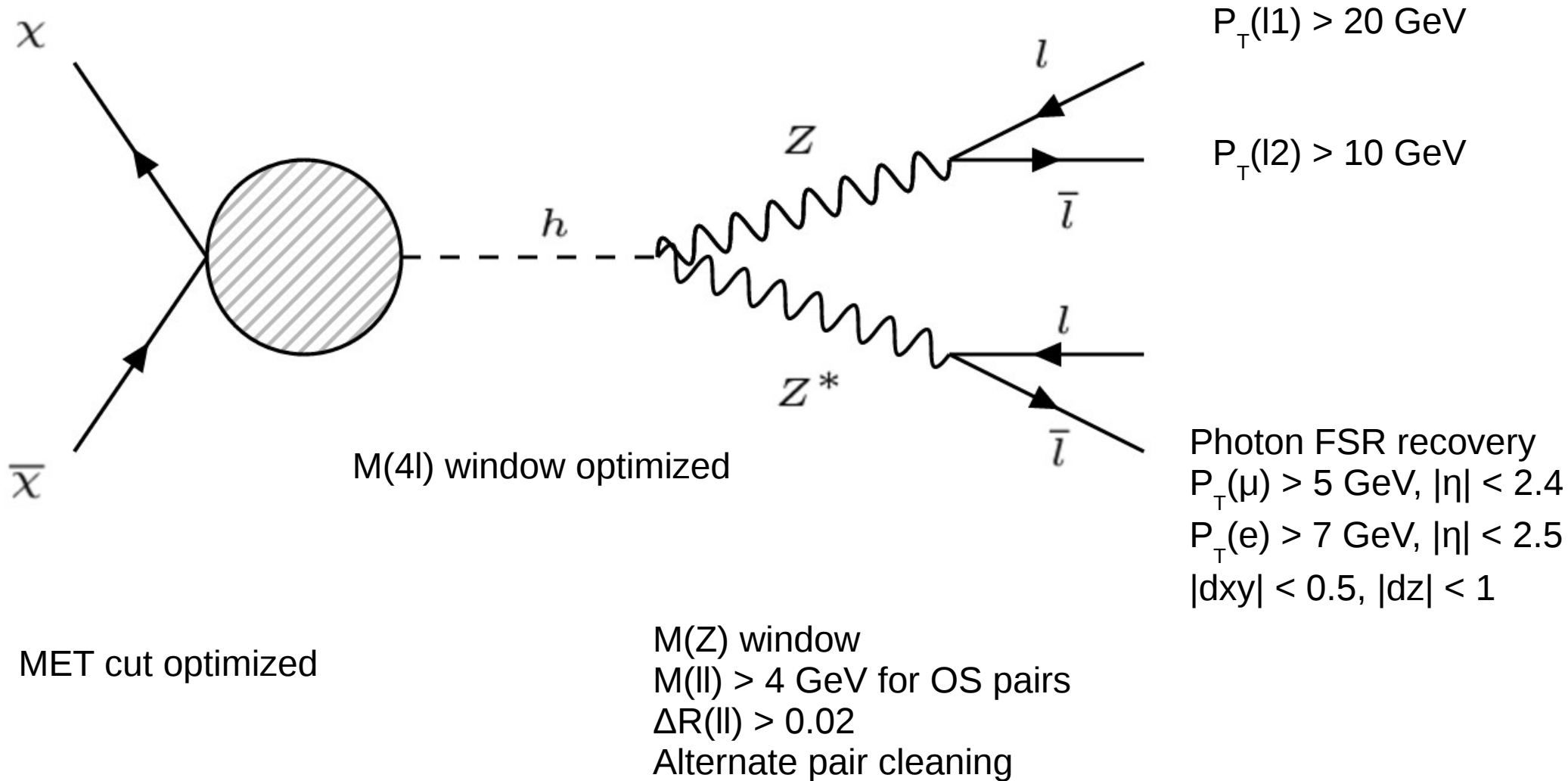
- “Discovery topology”
- Specific models motivate all mono-X searches

# Strategy and Samples

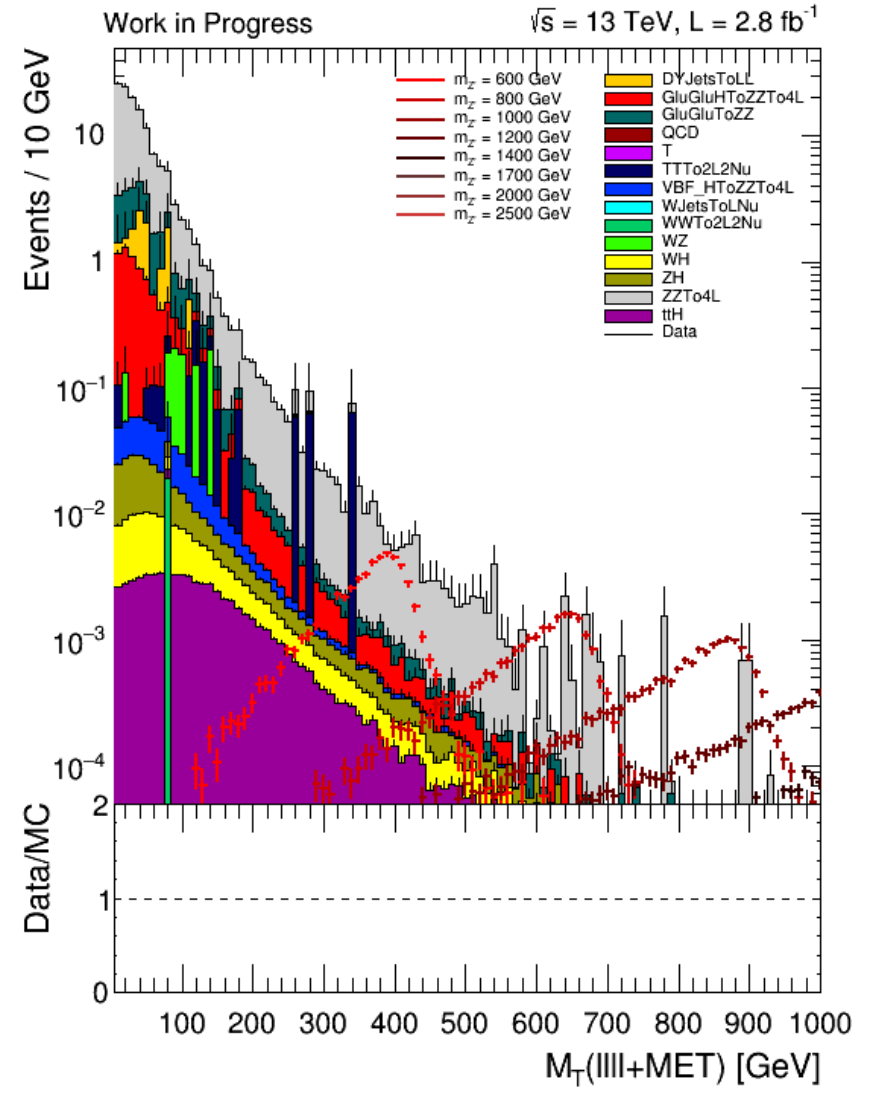
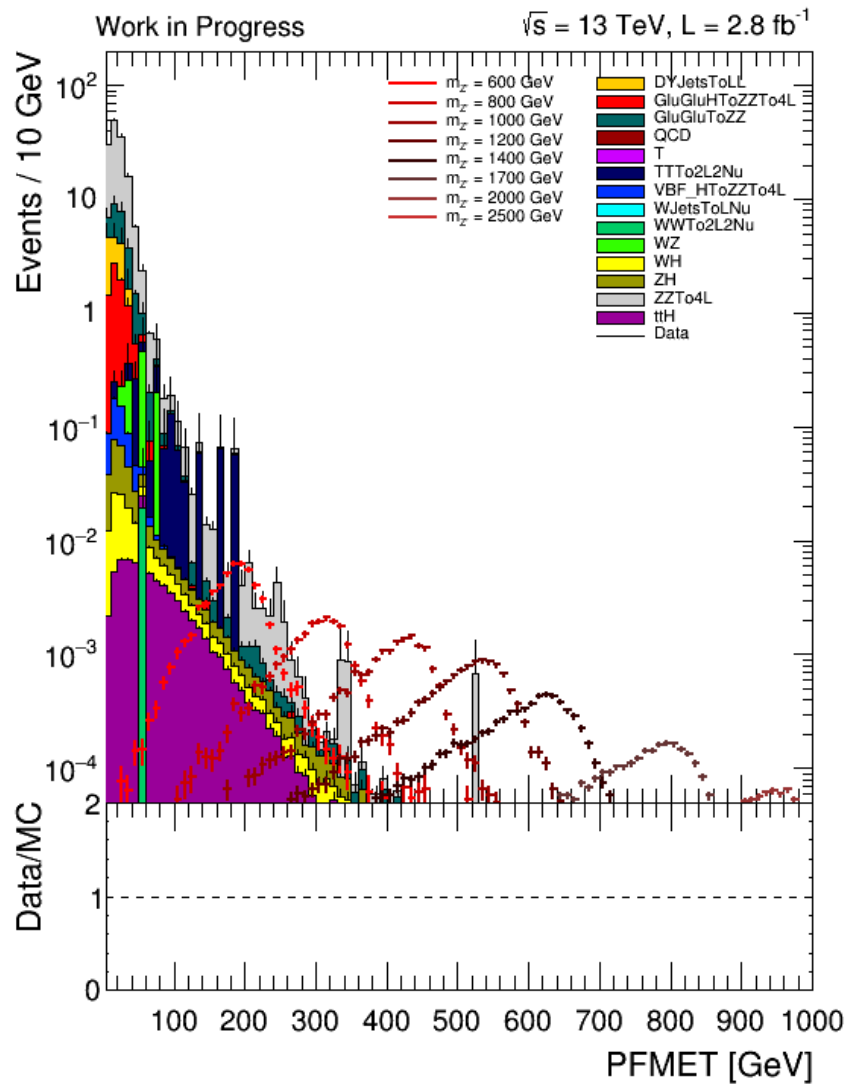
- **Analysis Strategy:**
  - Synchronize analysis with Run 2 SM  $H \rightarrow ZZ \rightarrow 4l$
  - Add additional selection steps motivated by signature (MET, DPHI, etc)
    - Optimize new selection
    - Study MET modeling and systematics
  - In the absence of events in signal region, set limits on cross section and model parameters
- **Signal:** Models based on feasibility study by Les Houches working group: Arxiv 1605.02684
- **Background:**
  - Irreducible, estimated from MC:
    - $ZH, Z \rightarrow \nu\nu, H \rightarrow ZZ \rightarrow 4l$  or  $ZH, Z \rightarrow ll, H \rightarrow ZZ \rightarrow ll\nu\nu$
    - $qq \rightarrow ZZ$  NNLO/NLO QCD and NLO/LO EWK k-factors applied
    - $gg \rightarrow ZZ$  NNLO/LO QCD k-factors applied + additional 10% uncertainty
  - Reducible, estimated from data with OS fake rate method:
    - Z+jets, tt+jets, QCD, etc  $\rightarrow Z+X$
- **Data:** 2.76/fb of 2015 datasets
  - multi-lepton HLT paths for trigger



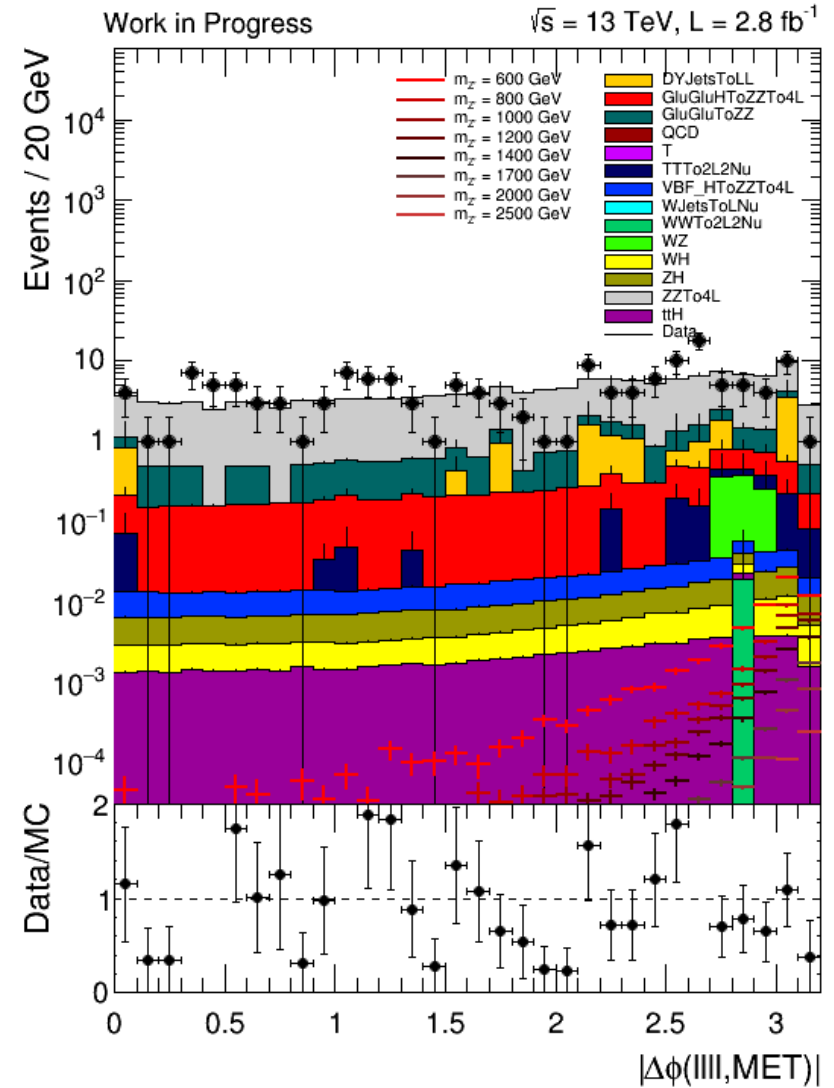
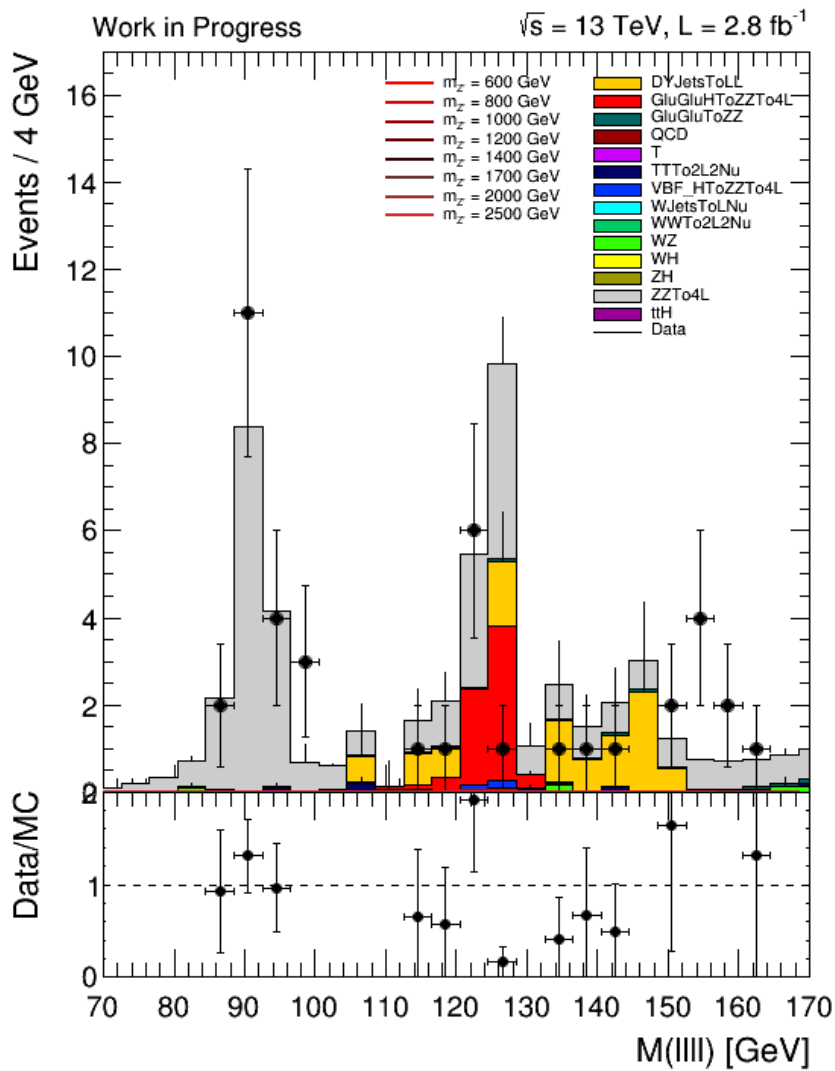
# Event Selection



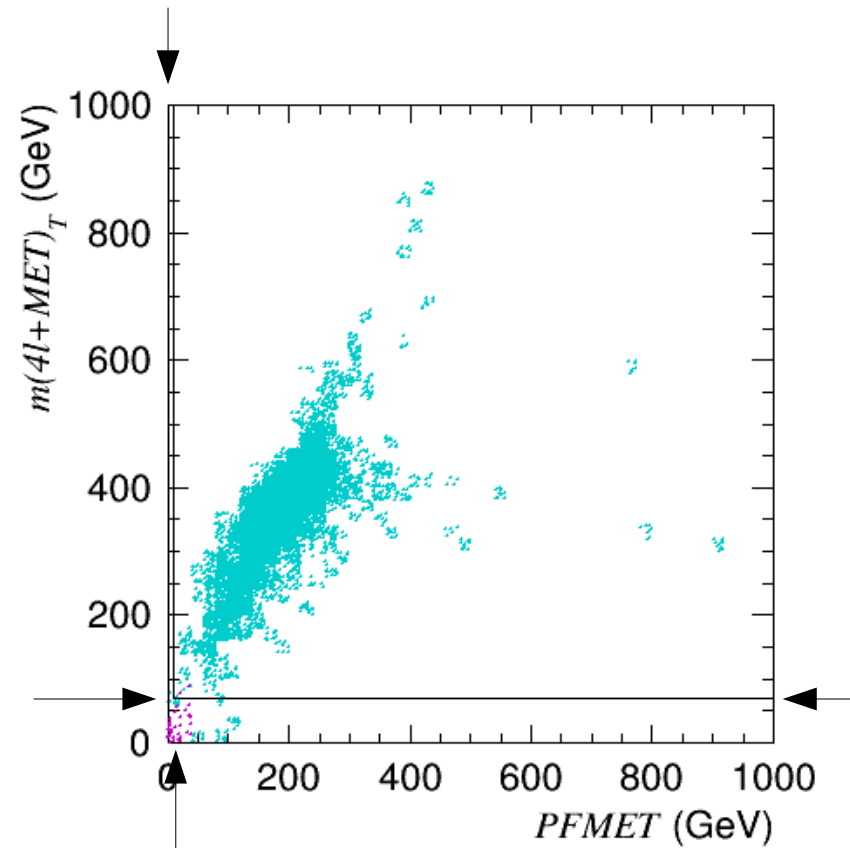
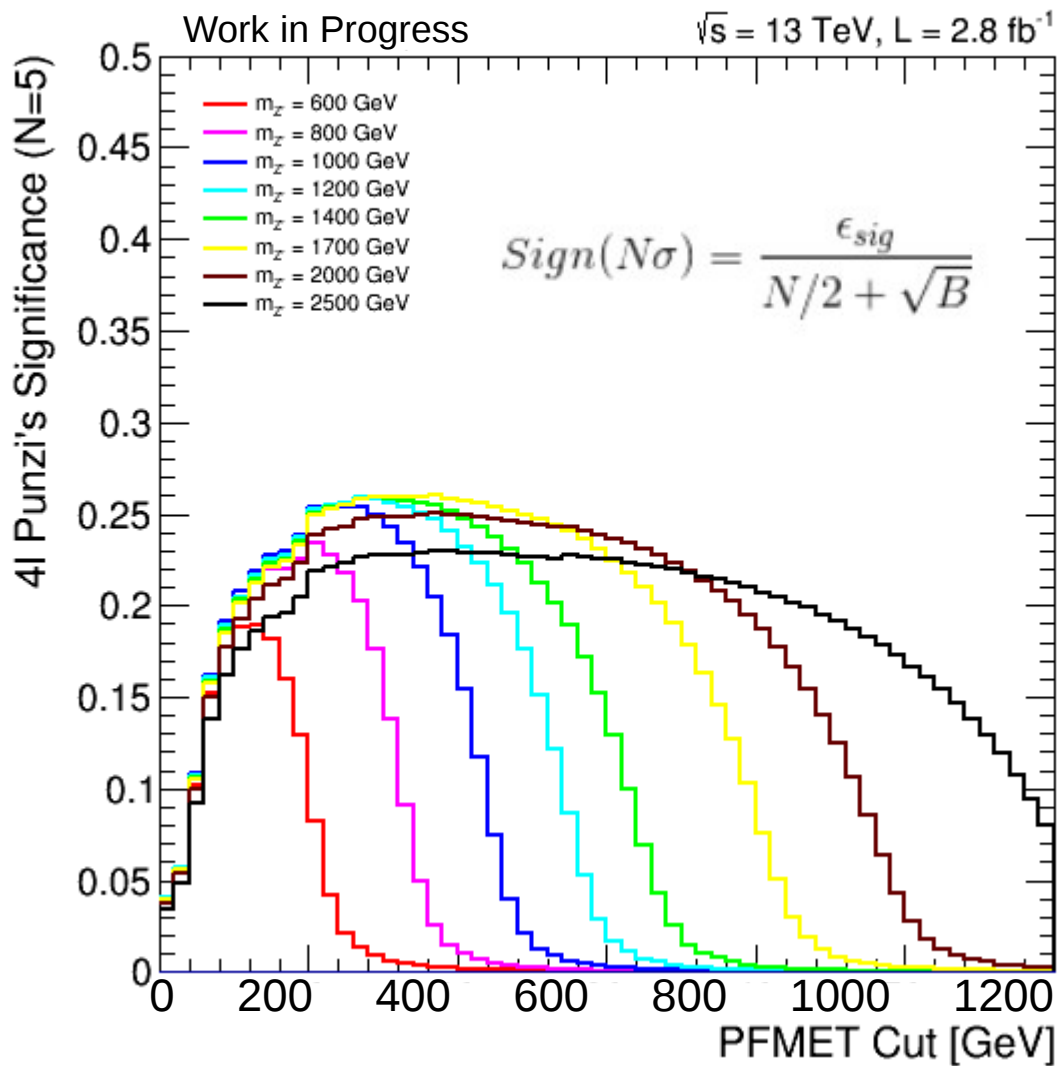
# Key Observables



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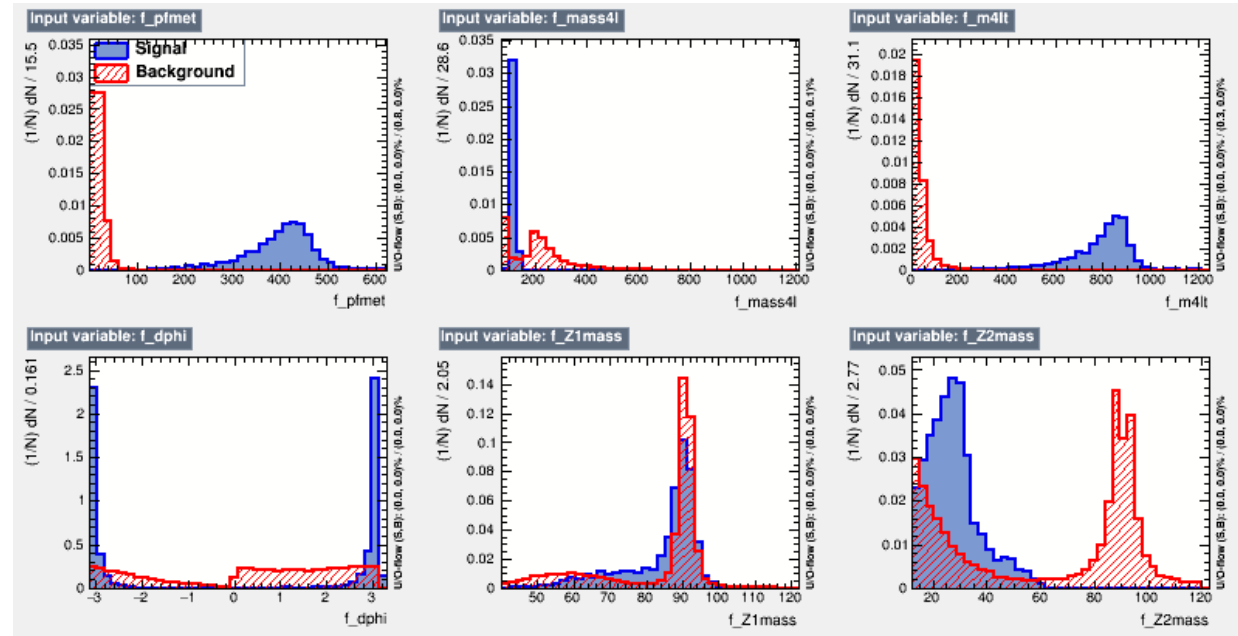
# Event Selection Optimization



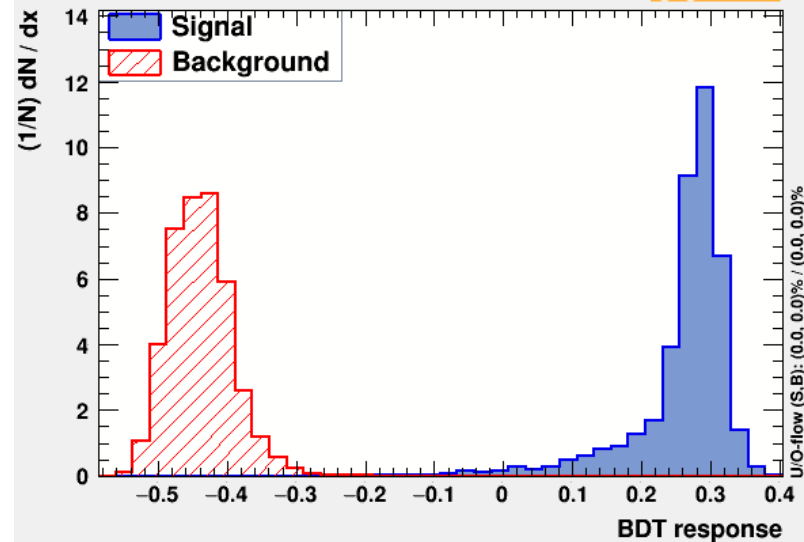


# Multivariate Analysis

- Alternative to optimizing box cuts on set of variables
  - Greater **discrimination power**
  - Increased **signal efficiency** after event selection
- **Train BDT** on set of kinematic distributions - inputs

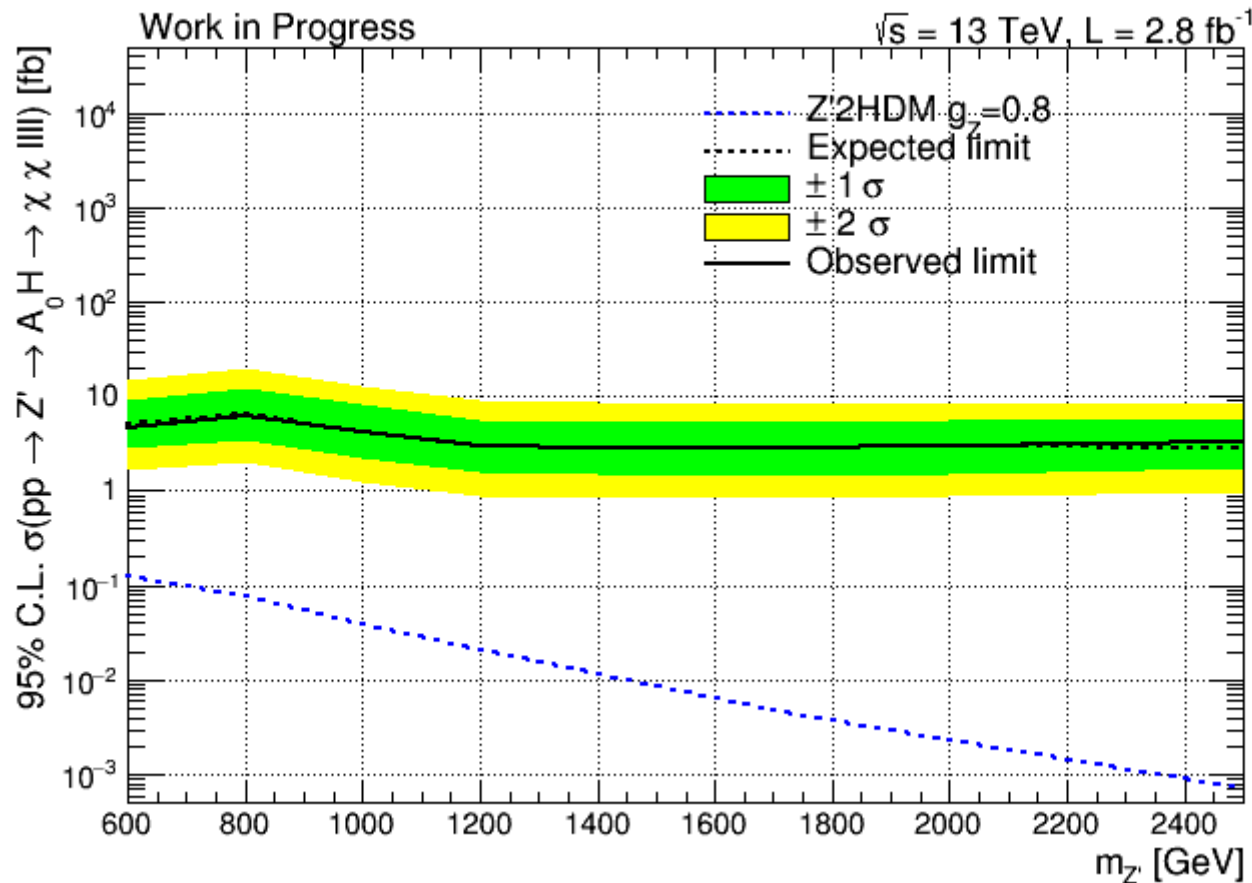


TMVA response for classifier: BDT



- **Test BDT** on all backgrounds and trained signal
- Optimize single cut on BDT response (Left)
  - Performance enhanced with higher  $M(Z')$  signals

# Cross Section Limits



- Upper limit based on [shape of PFMET](#) distribution after SM selection
- SM analysis [systematics](#) applied

- Channel comparison:
- $ZZ \sim 3 \text{ fb} / 1\text{E-}4 \sim 3\text{E}4 \text{ fb}$
- $\gamma\gamma \sim 5 \text{ fb} / 2\text{E-}3 \sim 3\text{E}3 \text{ fb}$
- $bb \sim 10 \text{ fb} / 6\text{E-}1 \sim 2\text{E}1 \text{ fb}$

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# Ongoing Work

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- Continuing to develop analysis techniques with **2015 data**
  - Selection optimization, MVA
  - Cross check cross section limits with alternate software
  - Background estimation from data, lepton fake rate measurements
  - Fake MET modeling, control regions
  - Combination with other Higgs decay channels
- Currently in big push to analyze **2016 data**
  - Update software, SM synchronization, MET filters, and Ntuple format
  - Process 2016 MC and data samples
  - Awaiting central production of additional signal models and mass points (2D)

