Constraints on H(inv) Decays From CMS

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Boston University

Higgs 2021 Conference

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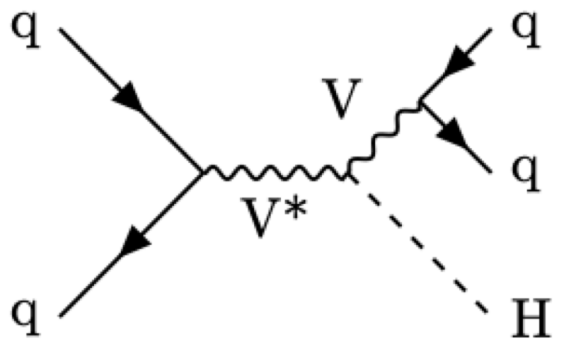
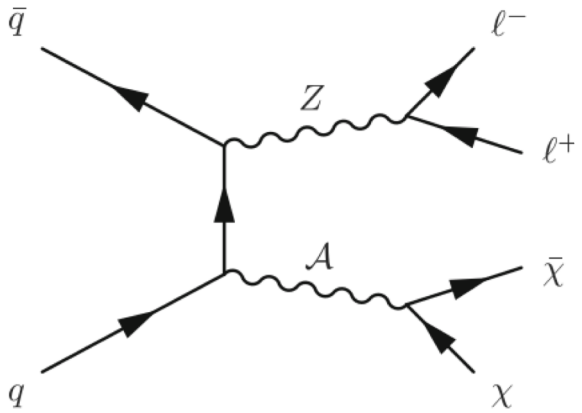
H(inv) Searches in CMS

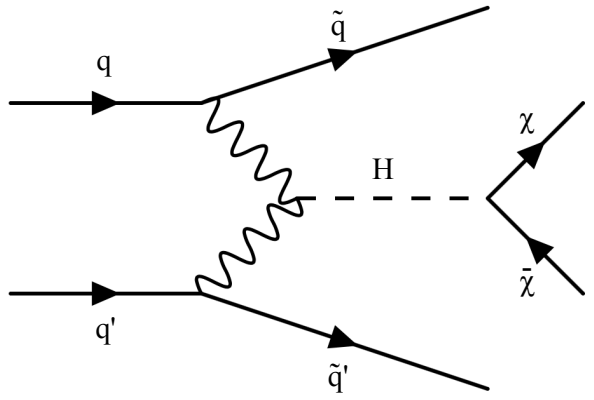
$H \rightarrow inv$ searches with Run2 data are done in CMS through several channels:



Monojet + Mono-V
arXiv:2107.13021



Mono-Z
EPJC 81, 13 (2021)



VBF H(inv)
CMS-PAS-HIG-20-003

Crucial to have precise estimations of backgrounds:

Make use of dedicated **control regions**

(e.g. $Z(ll) + jets$)

Simultaneous fit with all control and signal regions

Precise estimation of dominant backgrounds in **signal region**

(e.g. $Z(\nu\nu) + jets$)

H(inv) Searches in CMS

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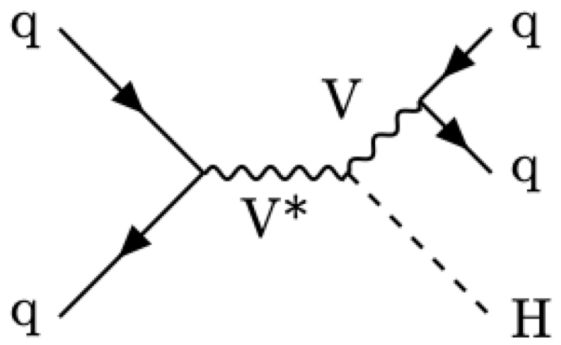

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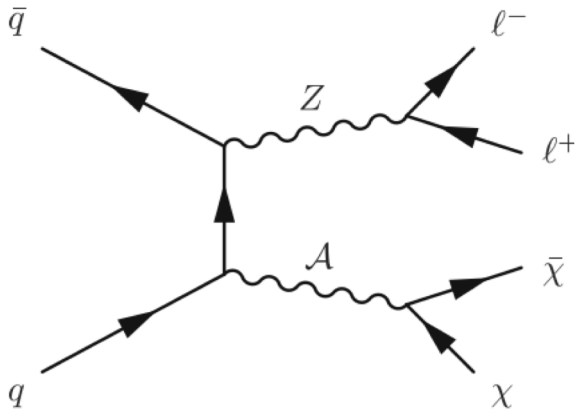

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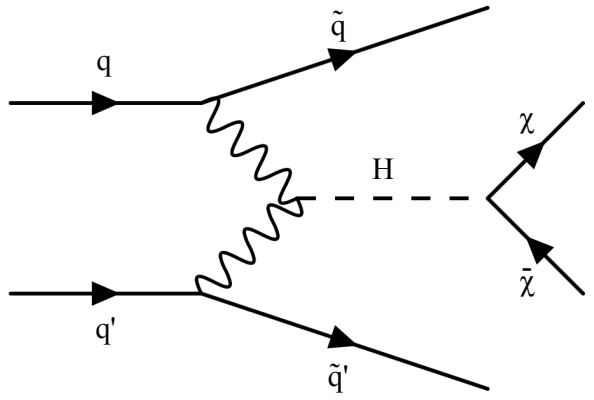


VBF H(inv)

CMS-PAS-HIG-20-003

Monojet + Mono-V: Strategy

arXiv:2107.13021

Signal signature:

One energetic & central jet

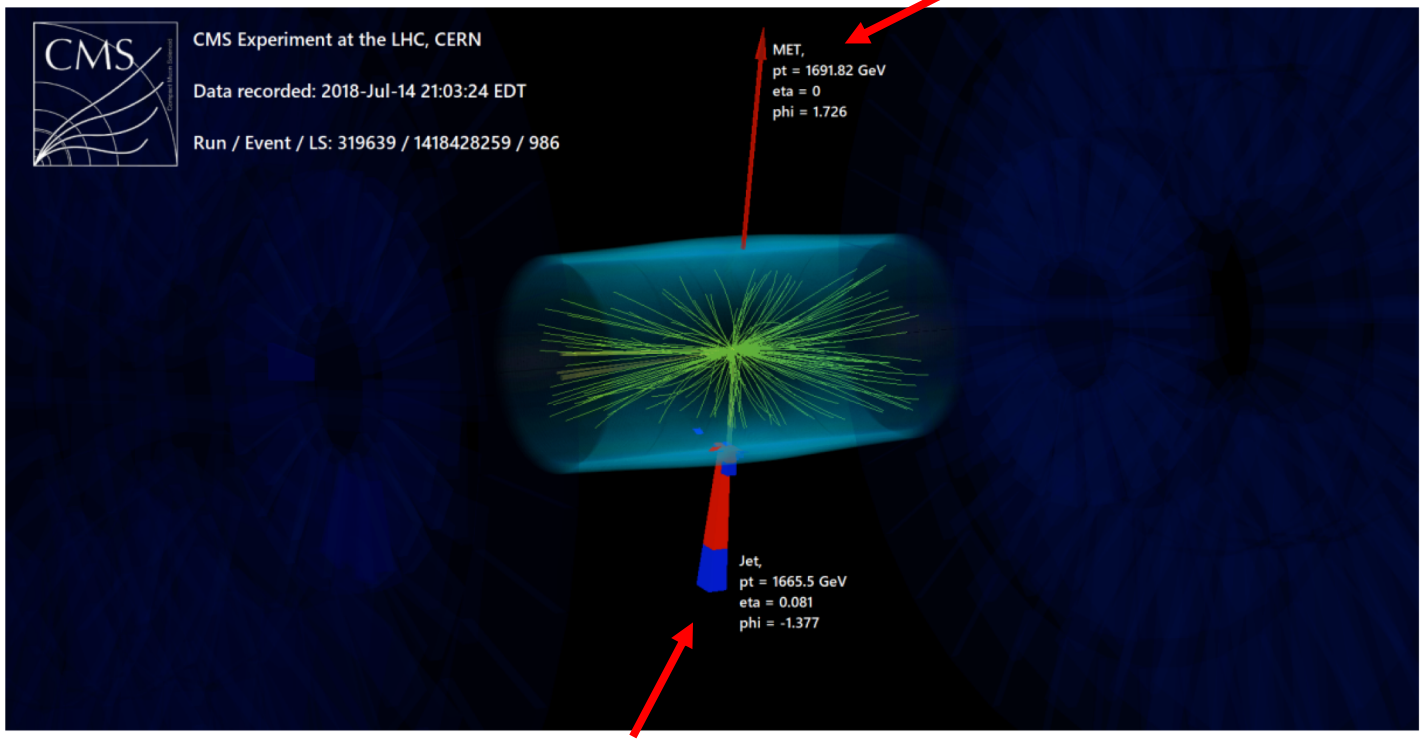
$+ p_T^{miss} > 250\ GeV$

Veto any other e, μ, τ, γ + b-jets

Two categories mainly differ on the jets being selected:

Monojet $\rightarrow$ AK4 jet $+ p_T^{miss}$

Mono-V $\rightarrow$ AK8 jet $+ p_T^{miss}$



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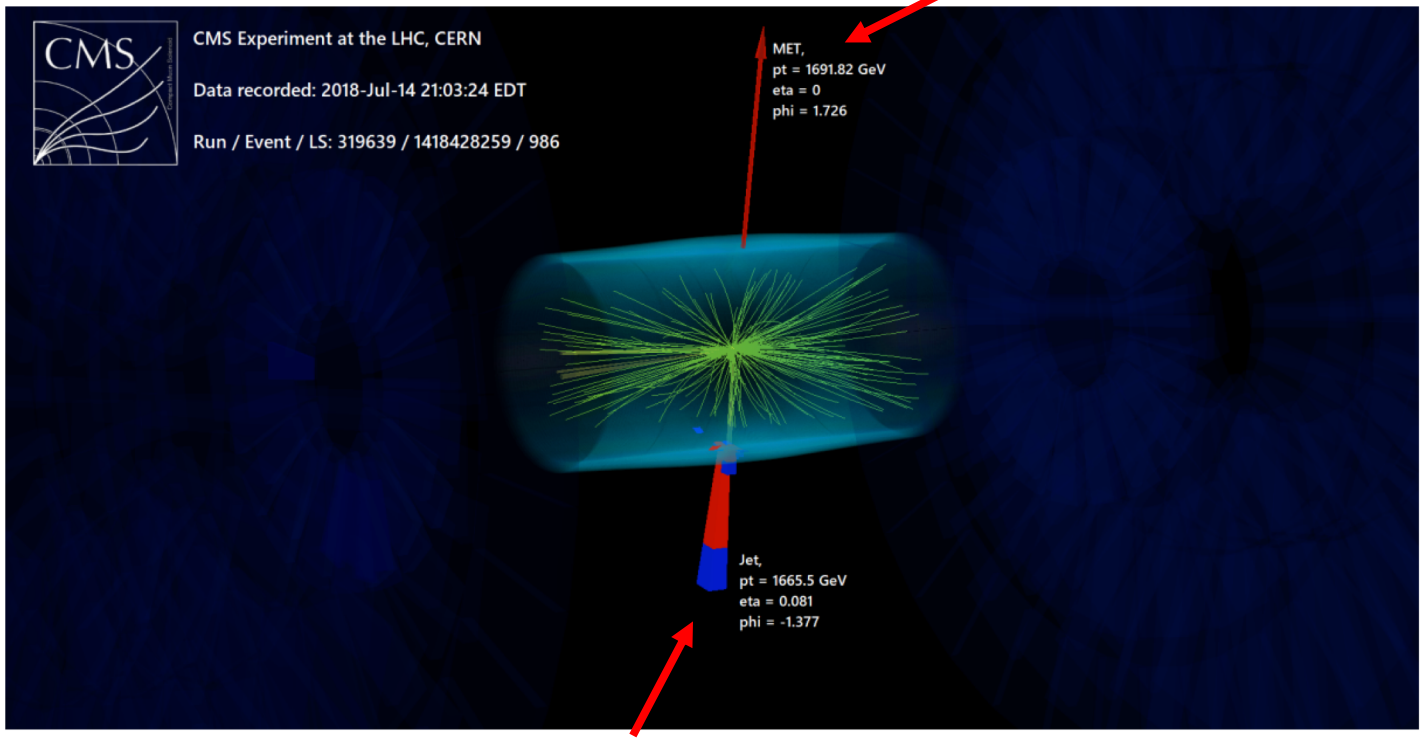
Details on the next slide

High p_T^{miss}



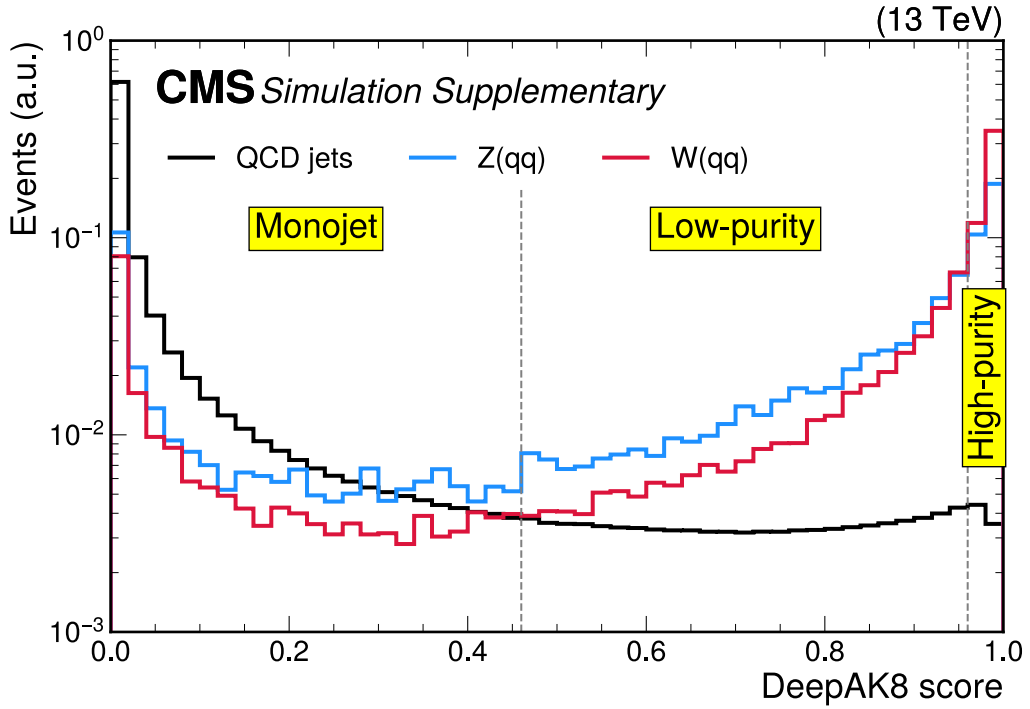
Energetic jet

Monojet + Mono-V: Categories

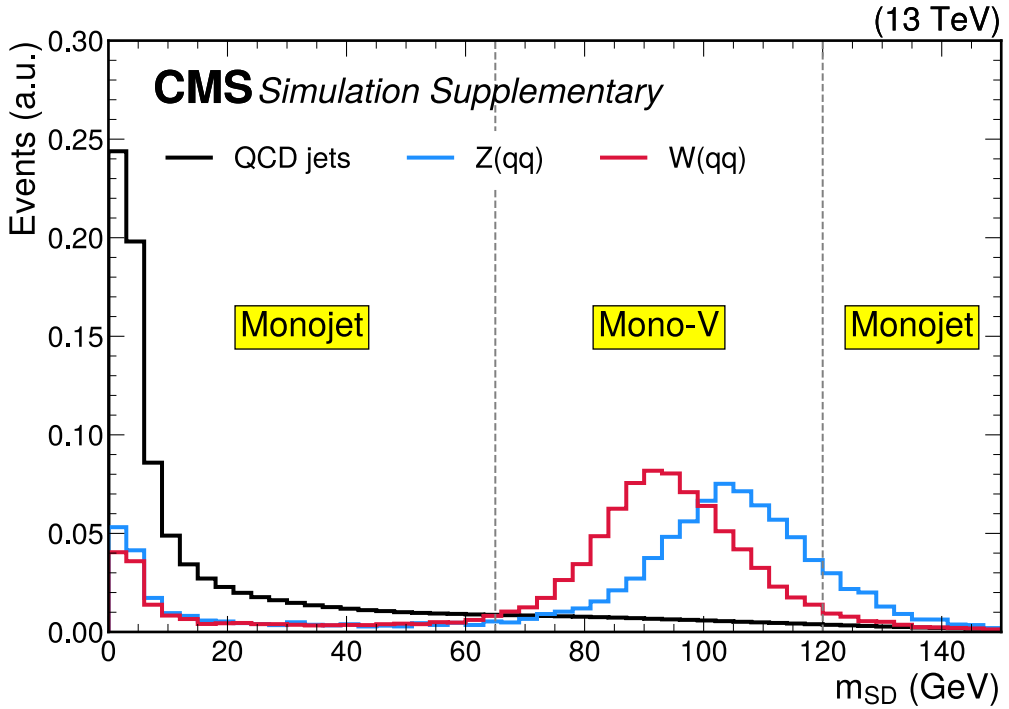
arXiv:2107.13021

Categories based on properties of the tagged jet:

DeepAK8 score of the tagged fat jet:



Softdrop mass of the tagged AK8 jet:



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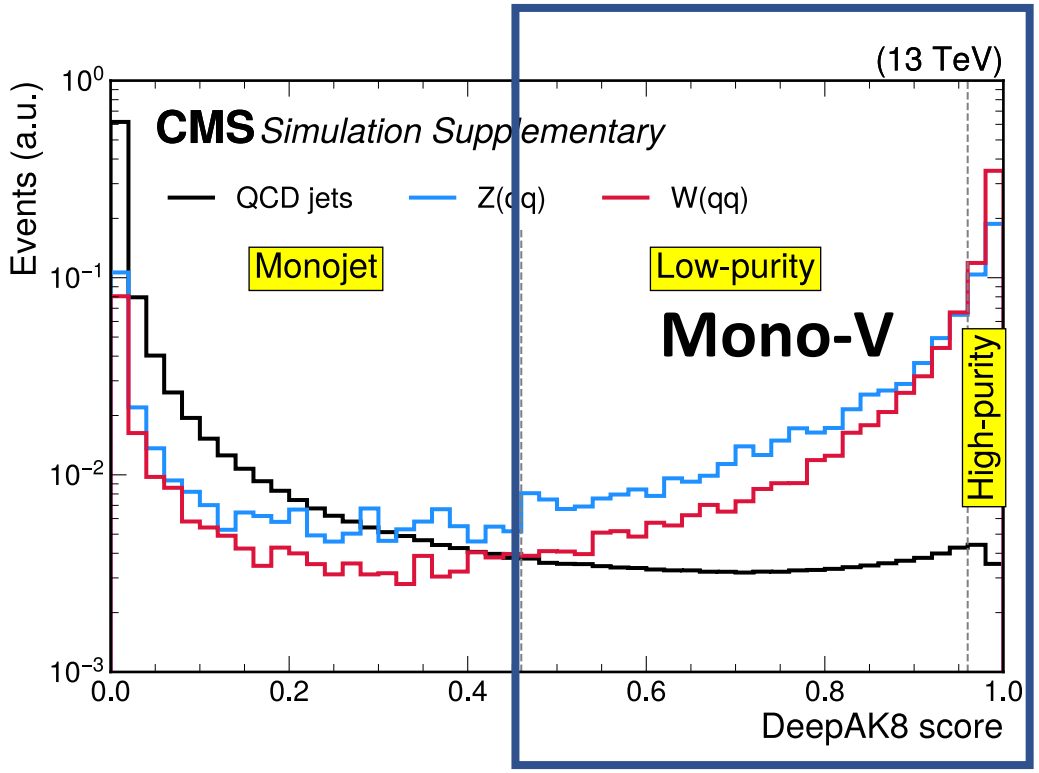
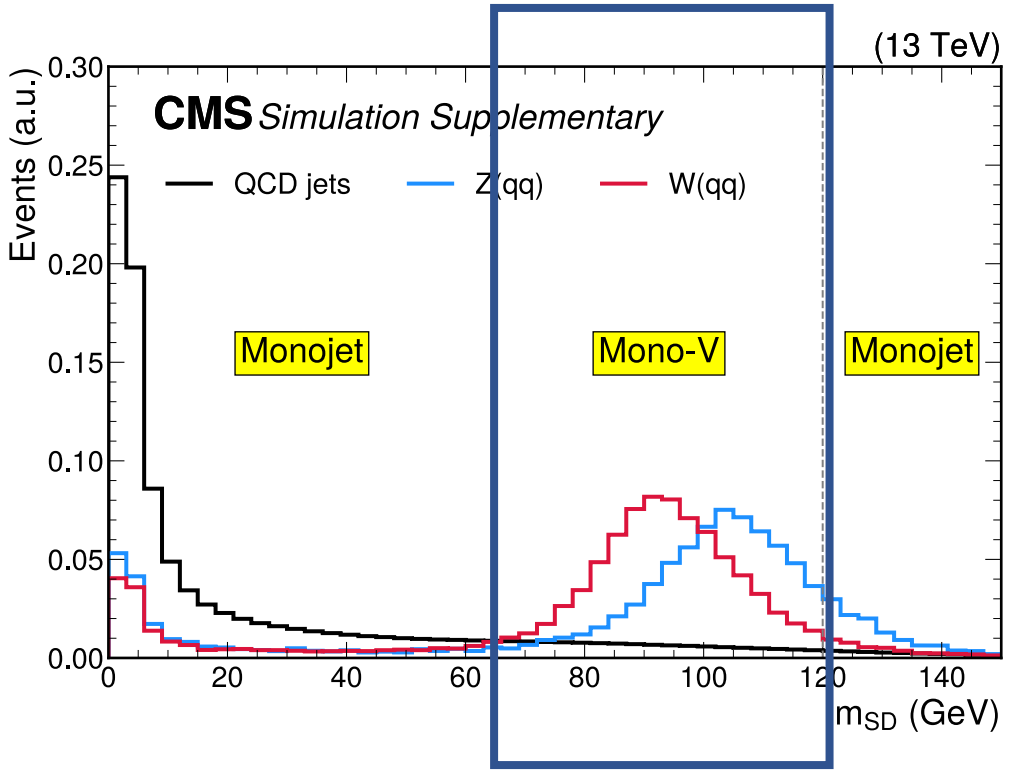


Mono-V Low/High Purity:
Categorized by the
DeepAK8 score of the jet

Softdrop mass of the tagged AK8 jet:



Mono-V: $65 < m_{SD} < 120\ GeV$
for the tagged AK8 jet

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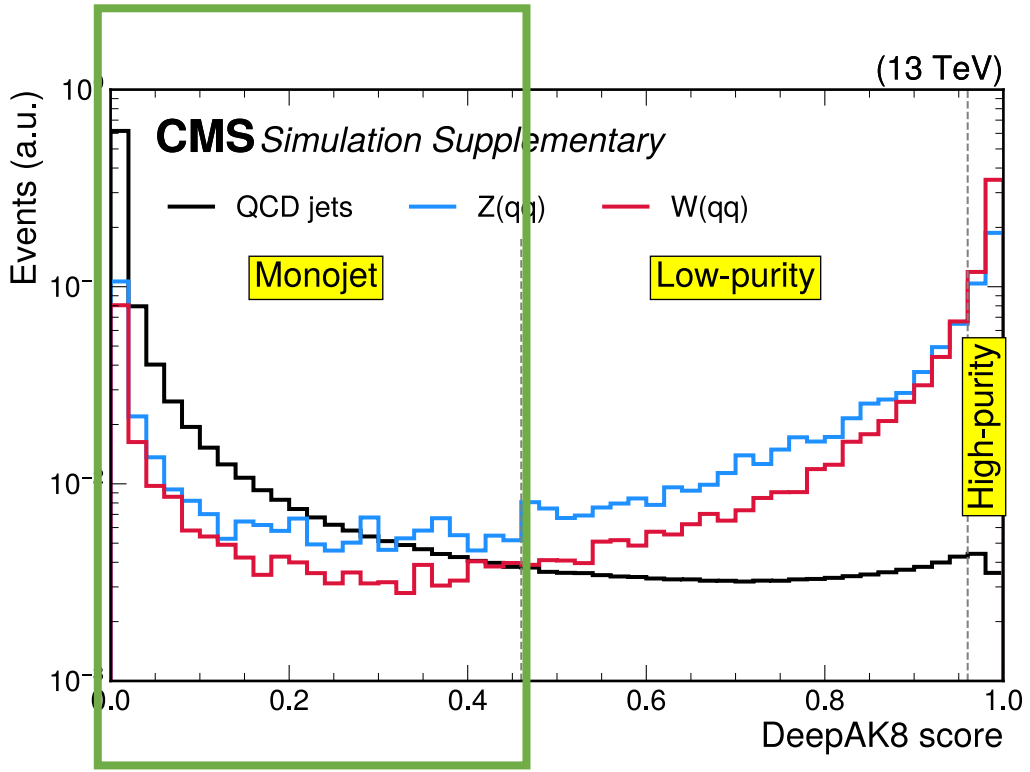

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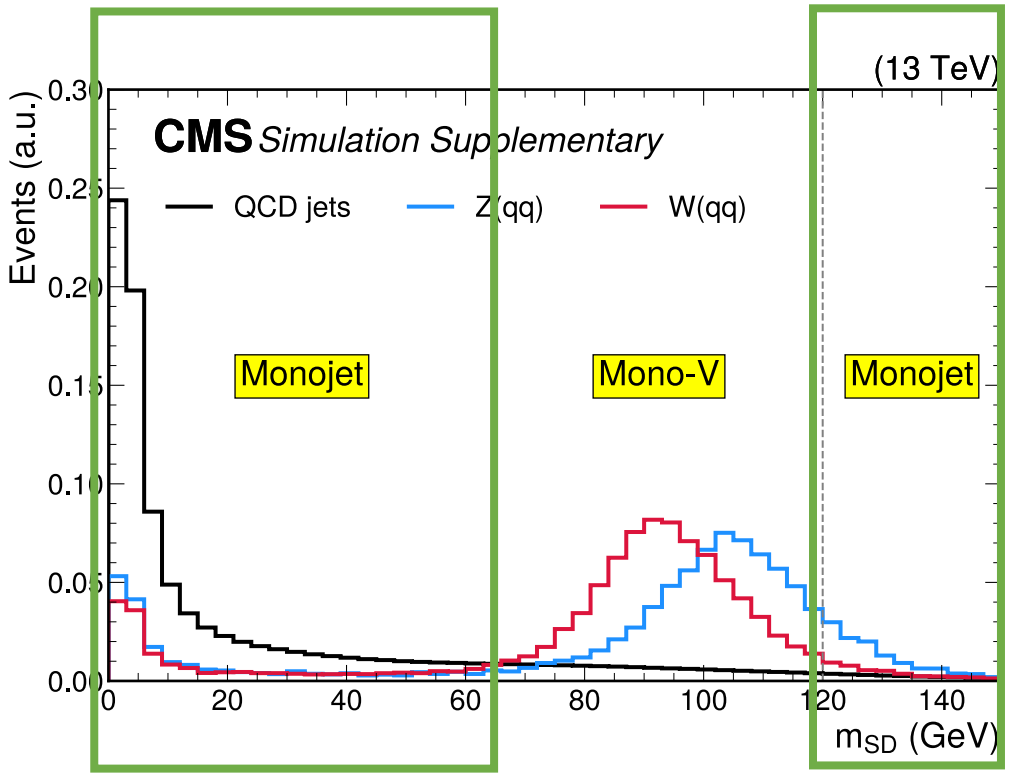

Events failing the mono-V selection are considered for monojet category

Monojet + Mono-V: Bkg Estimation

arXiv:2107.13021

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Veto any other e, μ, τ, γ + b-jets

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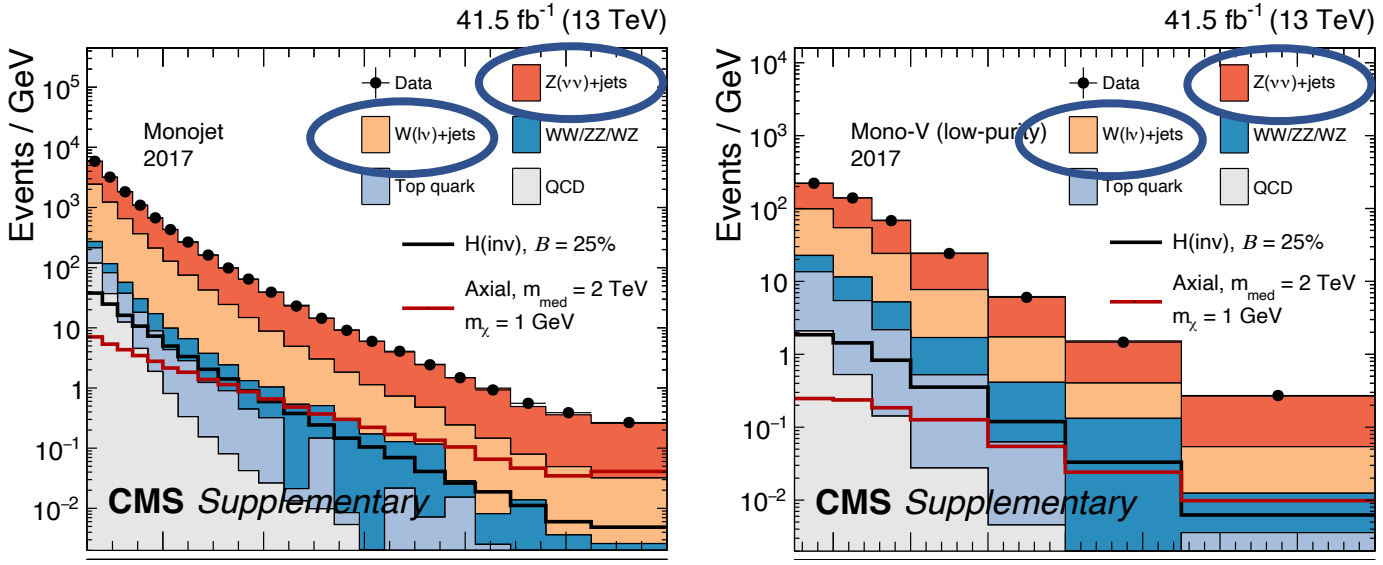
Signal region yields (2017) for monojet and mono-V:



Main backgrounds: $Z(\nu\nu), W(\ell\nu)$

Background estimation:

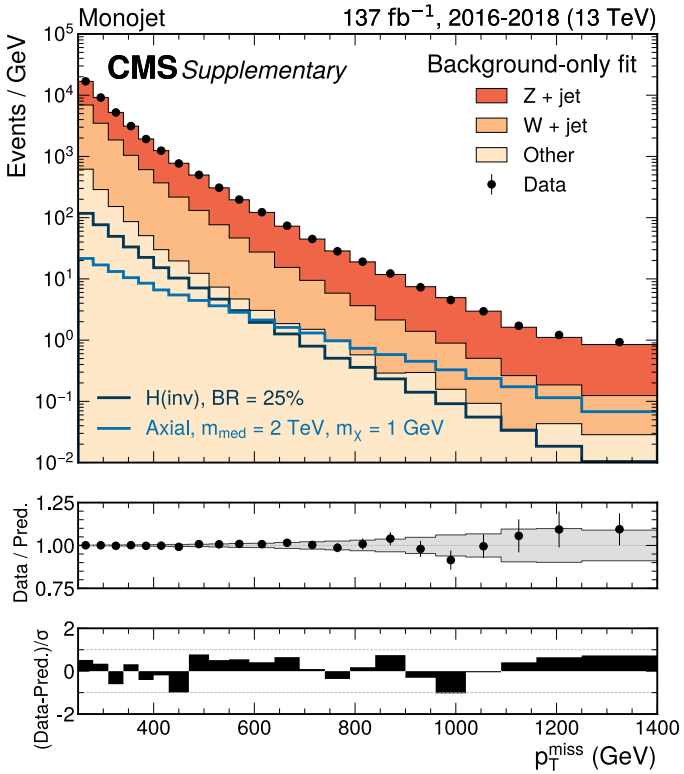
Estimate main backgrounds with a simultaneous fit of signal region and 5 control regions:

$1e/\mu, 2e/\mu, \gamma + jets$

Monojet + Mono-V: Results

arXiv:2107.13021

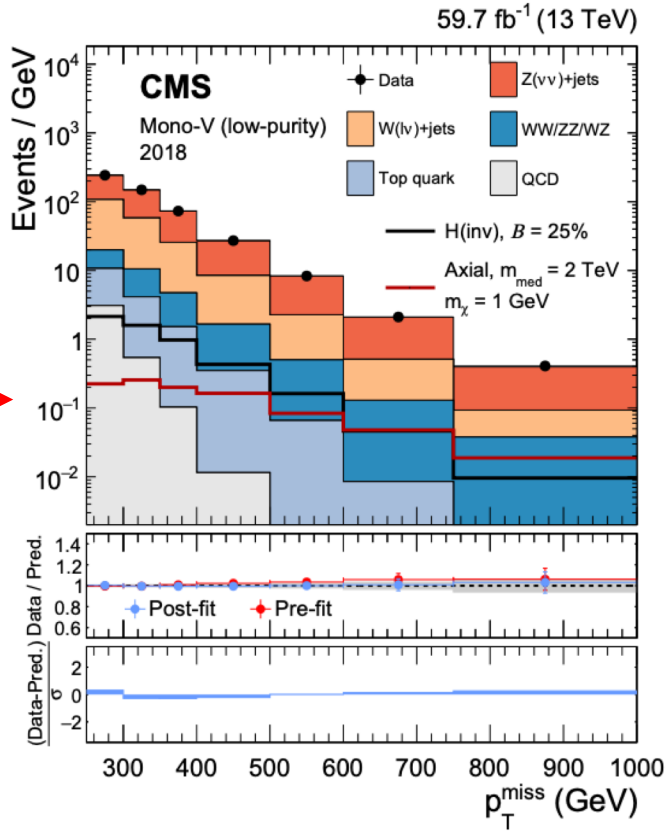
Monojet



Fit Results:

Good agreement observed between data and background estimations

Mono-V



No signal observation: Results are interpreted as exclusion limits on $B(H \rightarrow inv)$

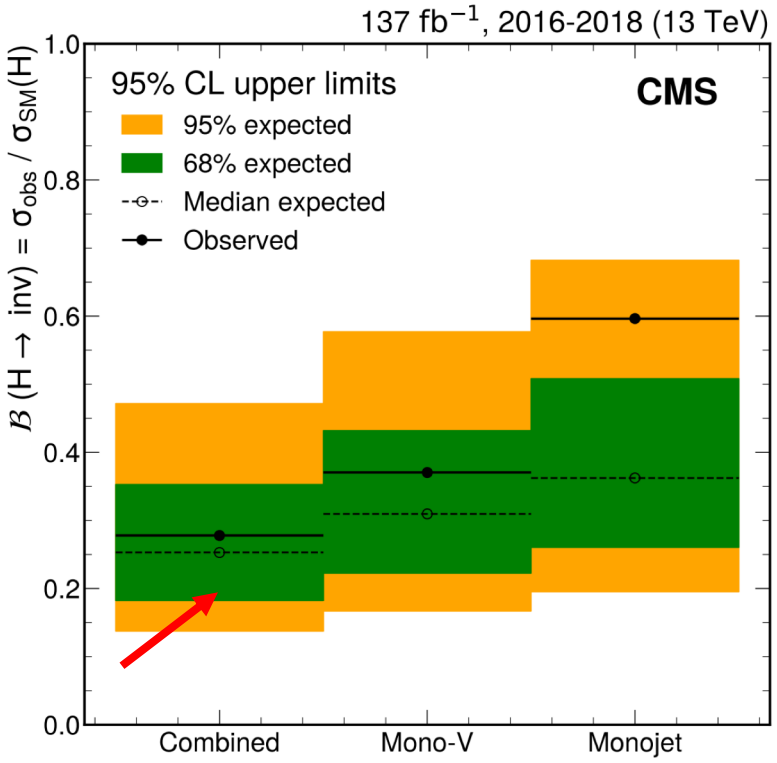
(amongst other interpretations!)

Monojet + Mono-V: Results

arXiv:2107.13021

With monojet and mono-V combined:

Reaching to 28% (25%) obs. (exp.) exclusion limit on $B(H \rightarrow inv)$



$\mathbf{1.9x}$ $\mathbf{(1.6x)}$ improvement in obs. (exp.) limits compared to previous result for the same channel

Most stringent limits from this channel up to date!

Monojet + Mono-V: Results

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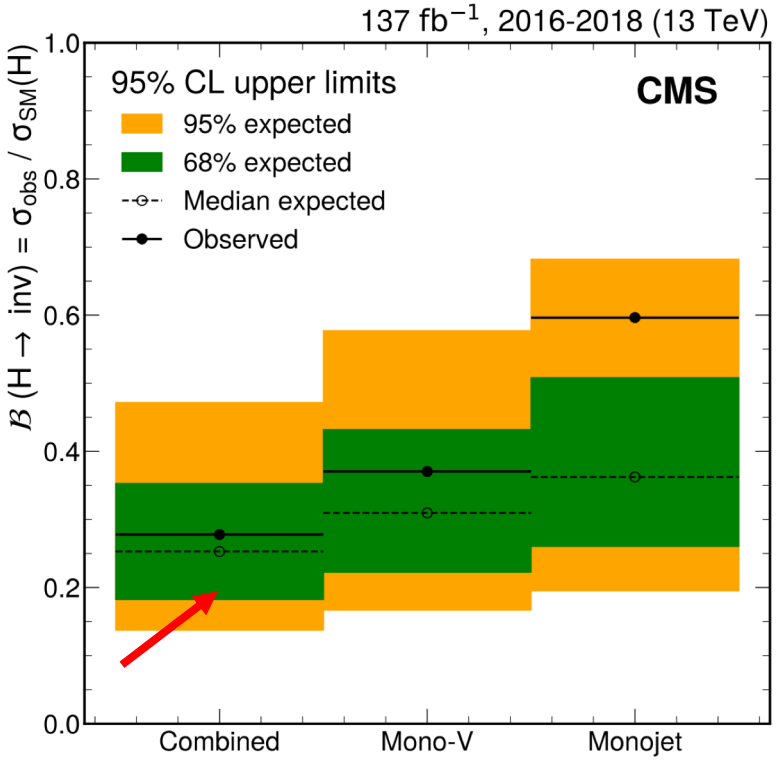


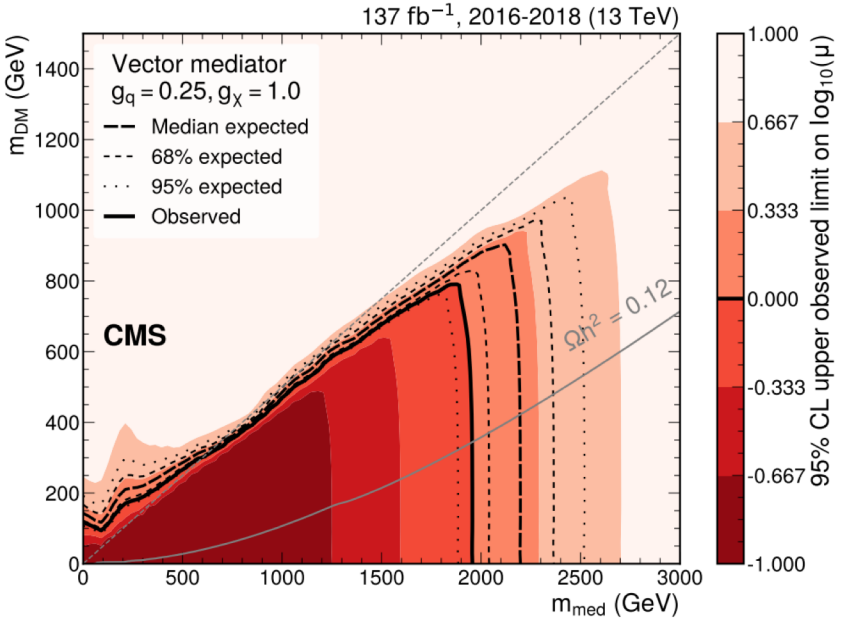
$\mathbf{1.9x}$ $\mathbf{(1.6x)}$ improvement in obs. (exp.) limits compared to previous result for the same channel

Most stringent limits from this channel up to date!

→ Further interpretations in the reference

DM Interpretation

Exclusion limits are calculated as a function of DM and mediator (spin-1) masses:



→ $m_{med} \approx 1.95\ TeV$ excluded for low m_{DM}

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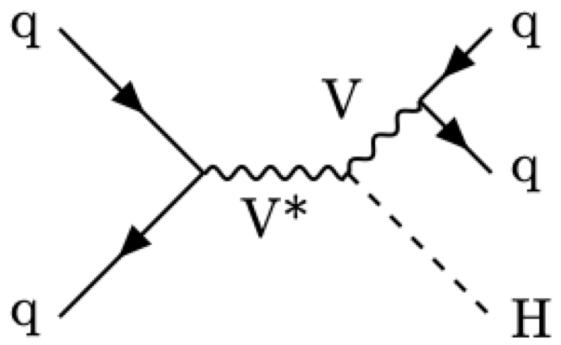

Monojet + Mono-V

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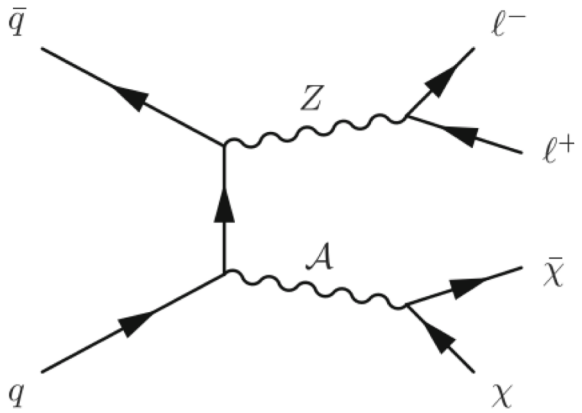

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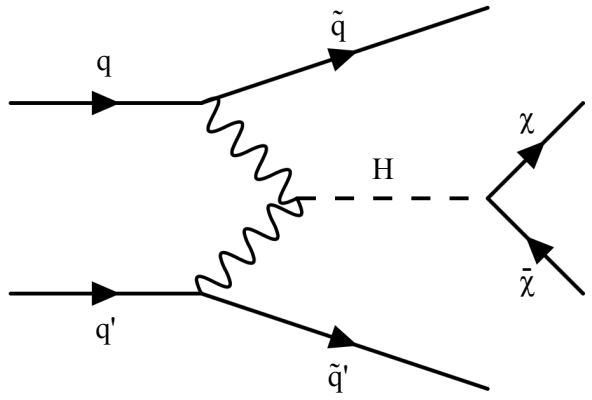

VBF H(inv)

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Mono-$Z(\ell\ell)$: Strategy

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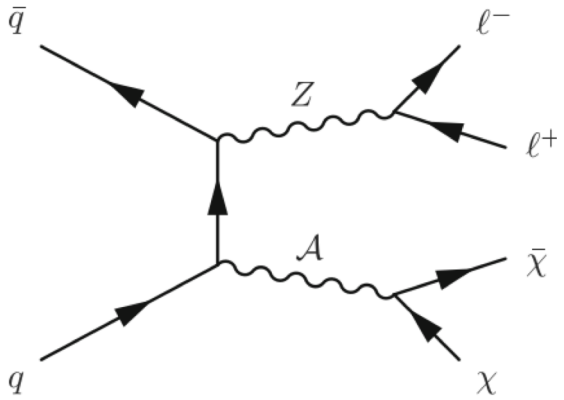
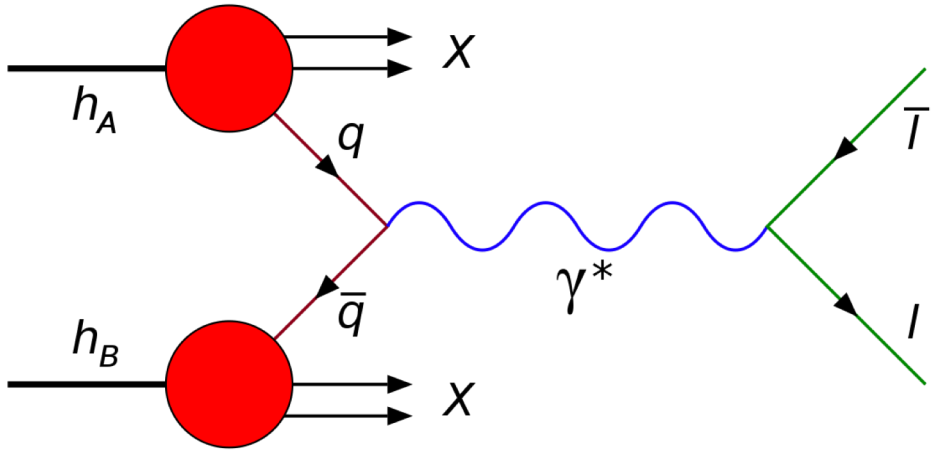


Signature: Two e/μ from Z decay + p_T^{miss}

Important backgrounds:

Drell-Yan production @ low p_T^{miss}



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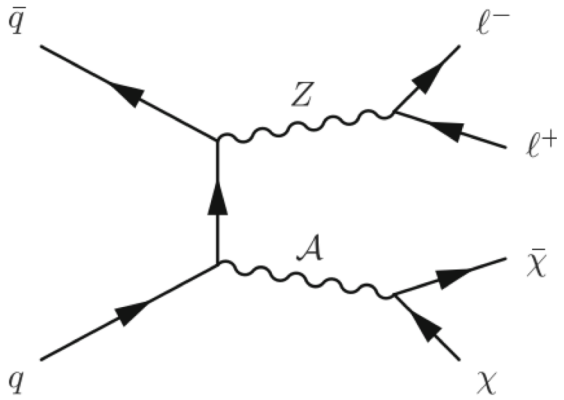

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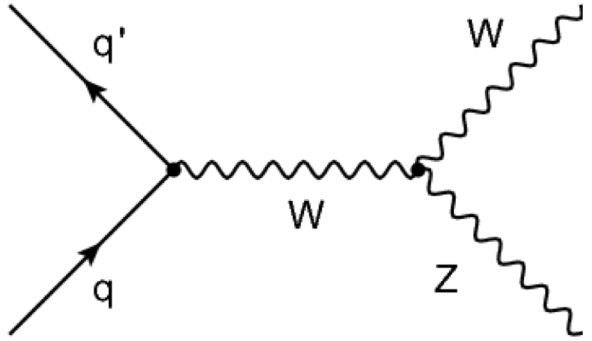
WZ process with a lost lepton



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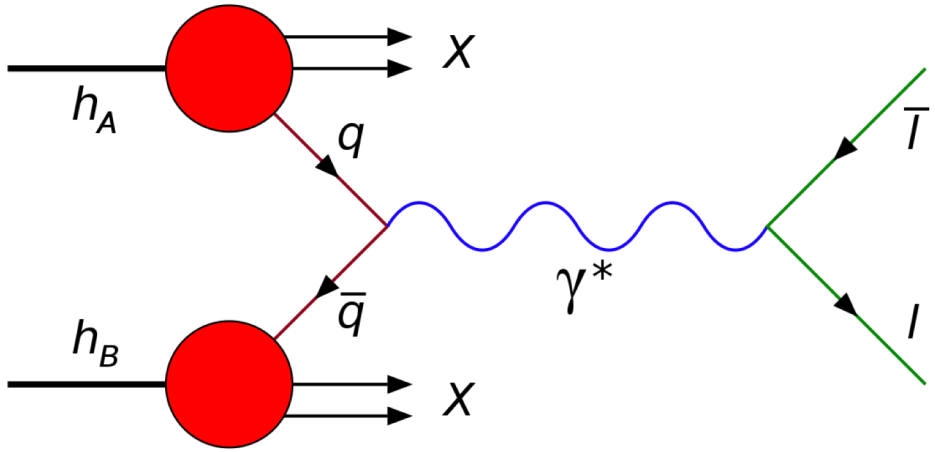

Mono-$Z(\ell\ell)$: Strategy

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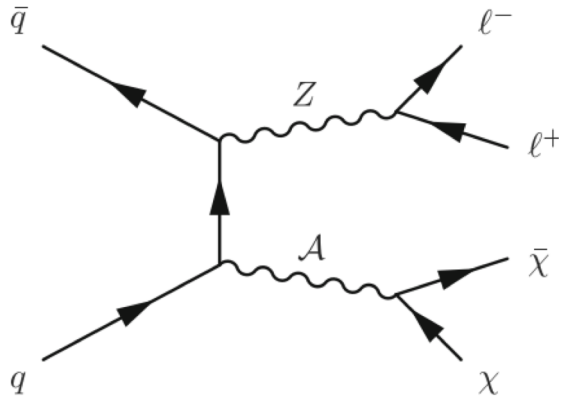

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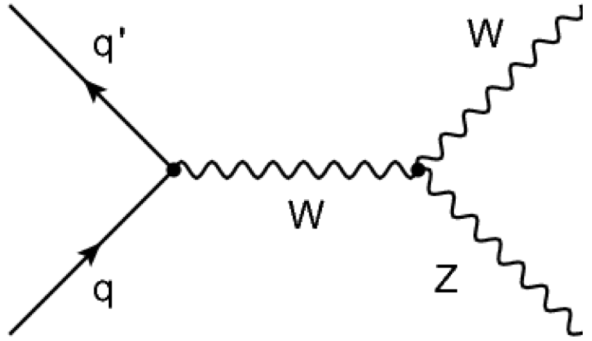

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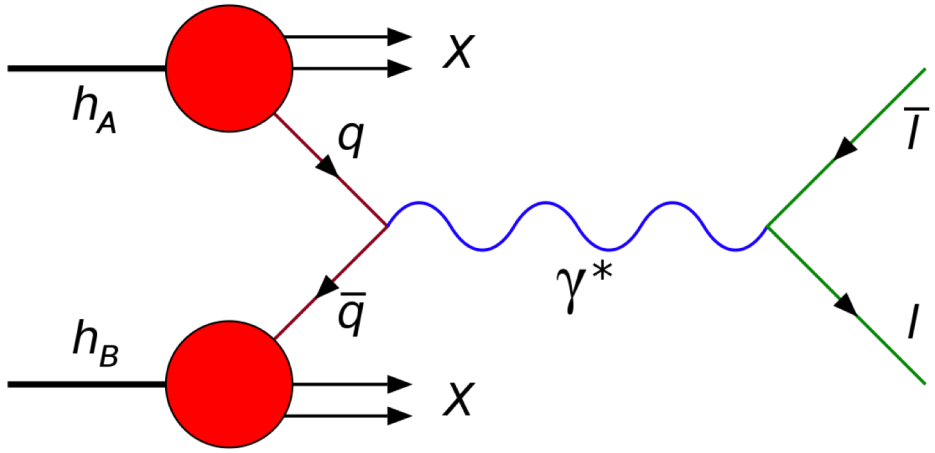
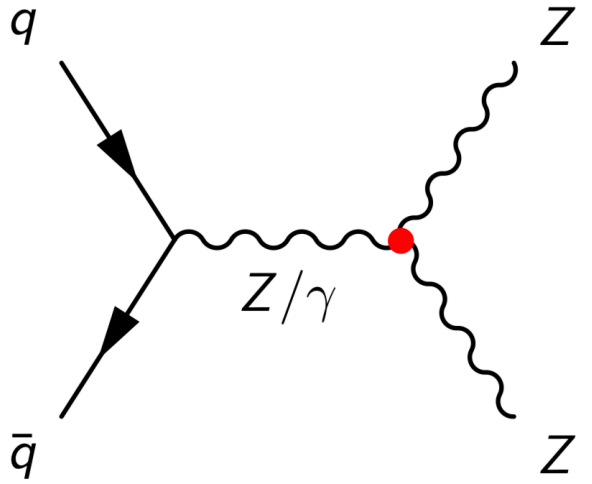


$ZZ \rightarrow 2\ell, 2\nu$



Mono-$Z(\ell\ell)$: Bkg Estimation

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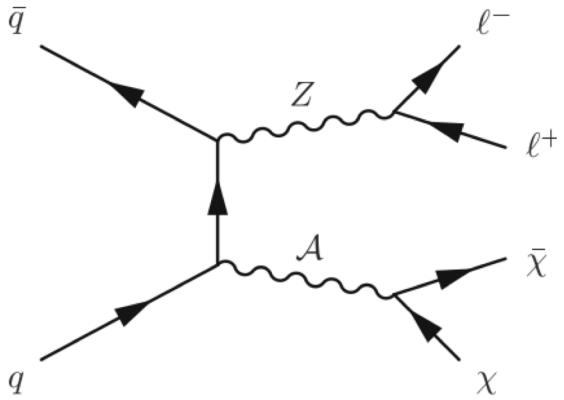


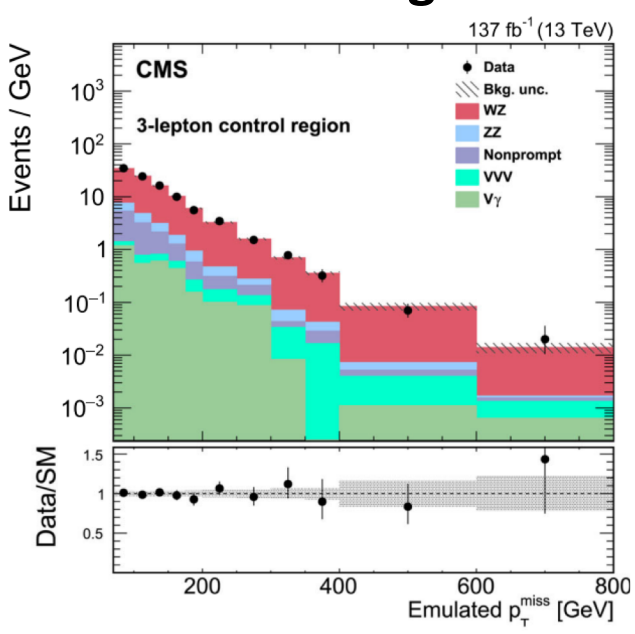
Signature: Two e/μ from Z decay + p_T^{miss}

Background estimation:

Set up dedicated control regions

→ Use a maximum-likelihood fit across all regions to get the final yields in the SR

WZ-enriched control region



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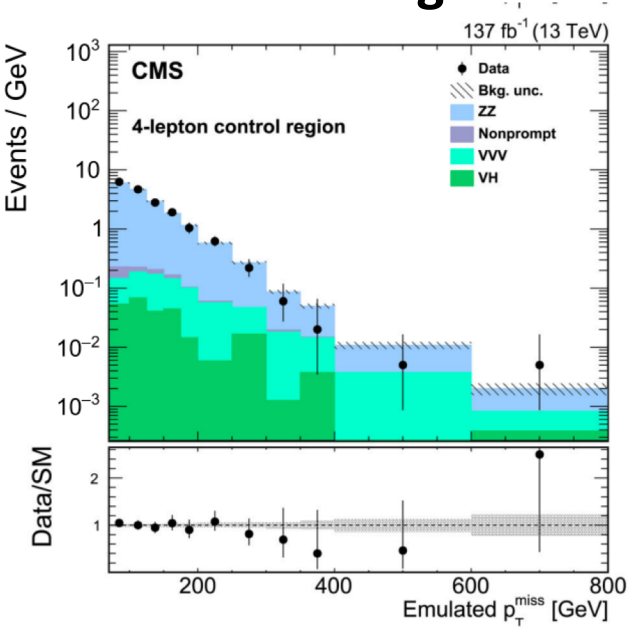

Use control regions to estimate WZ, ZZ and DY backgrounds in the signal region

Mono-$Z(\ell\ell)$: Results

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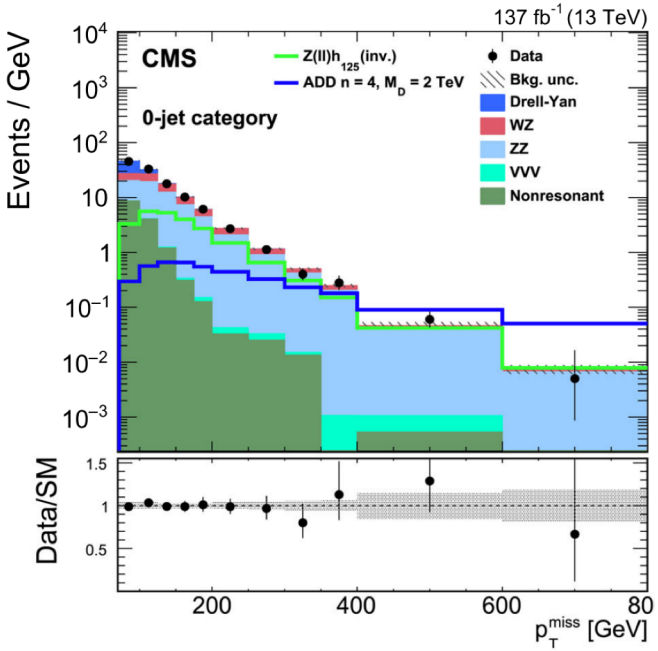
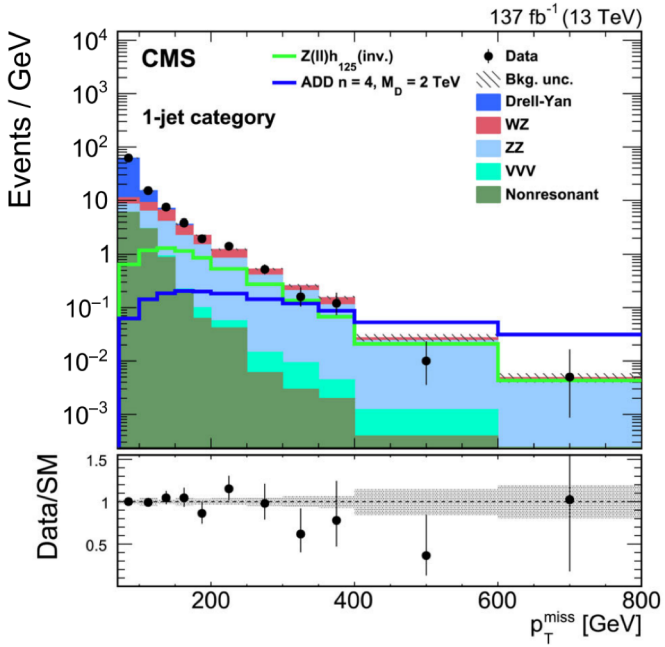
Events in signal region are further divided into 0-jet and 1-jet categories:

(take different S/B ratios into account, details in backup)

0-jet category



1-jet category



Good agreement between data and background estimation

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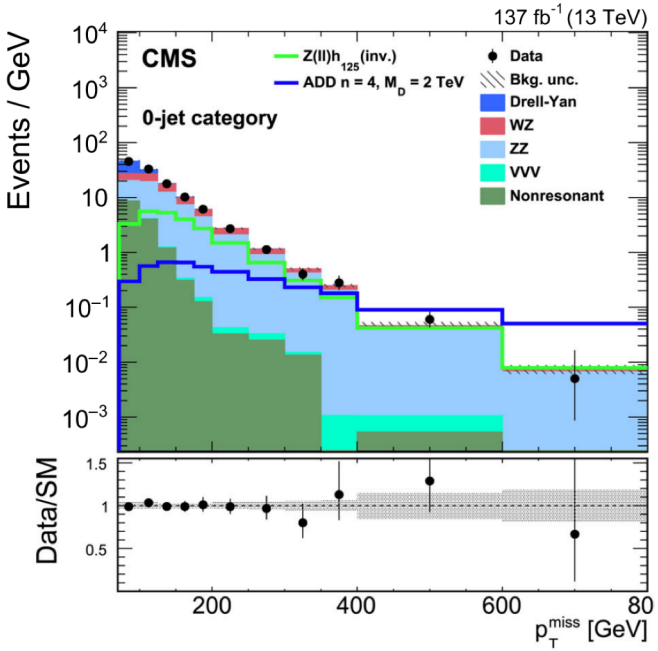

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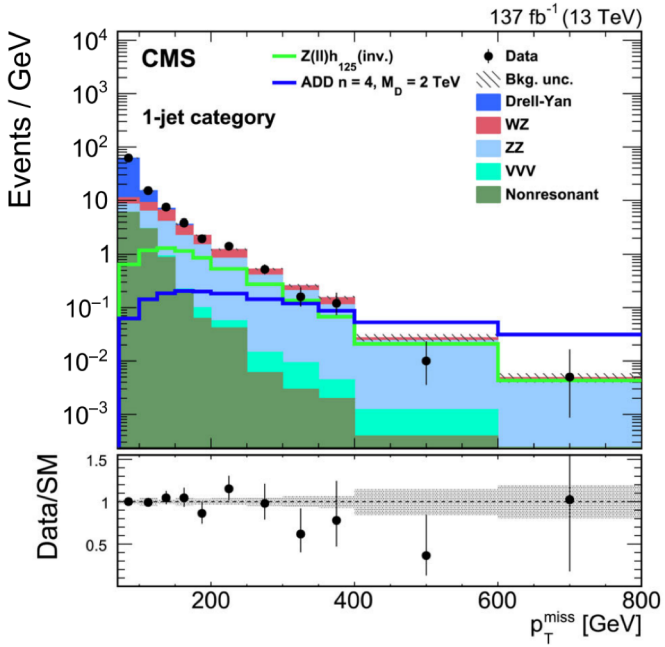


Good agreement between data and background estimation

→ Results interpreted as exclusion limits on $B(H \to inv)$

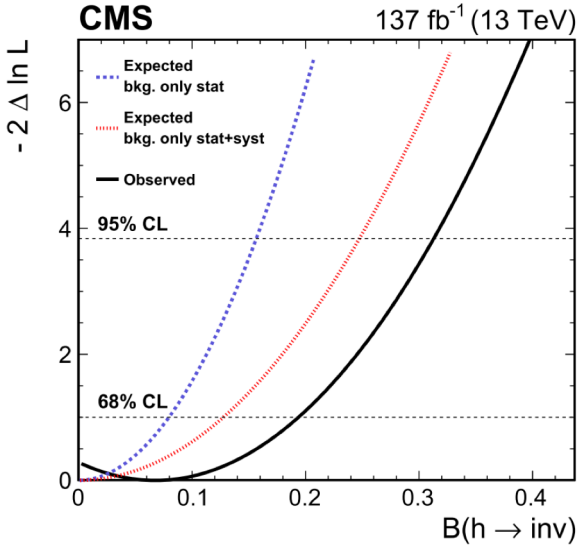
(amongst other interpretations!)

H(inv) interpretation

Limits on $B(H \to inv)$:

29% observed & 25% expected

$\approx 1.7x$ improvement over the previous CMS results for mono-Z!



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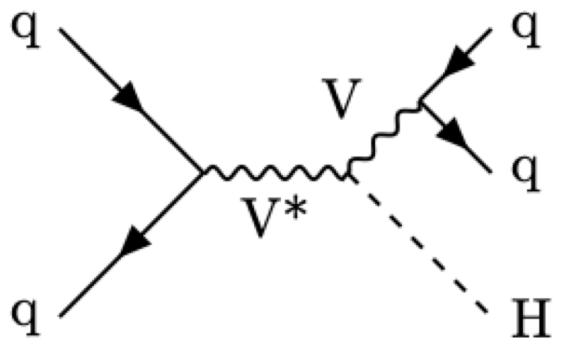
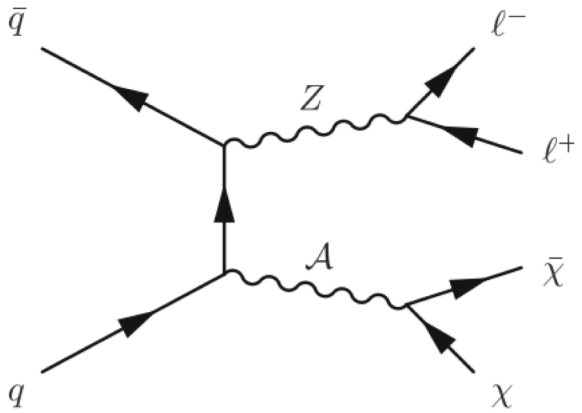


Monojet + Mono-V

arXiv:2107.13021



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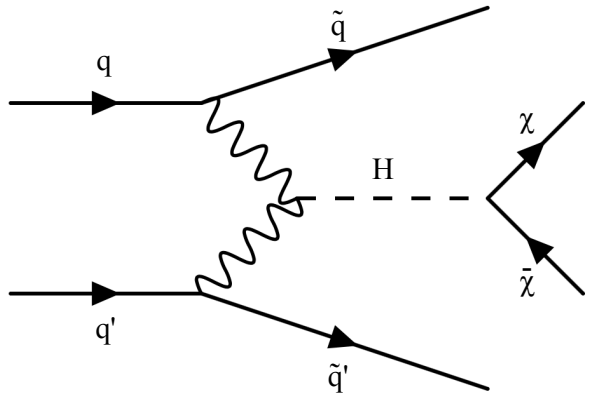
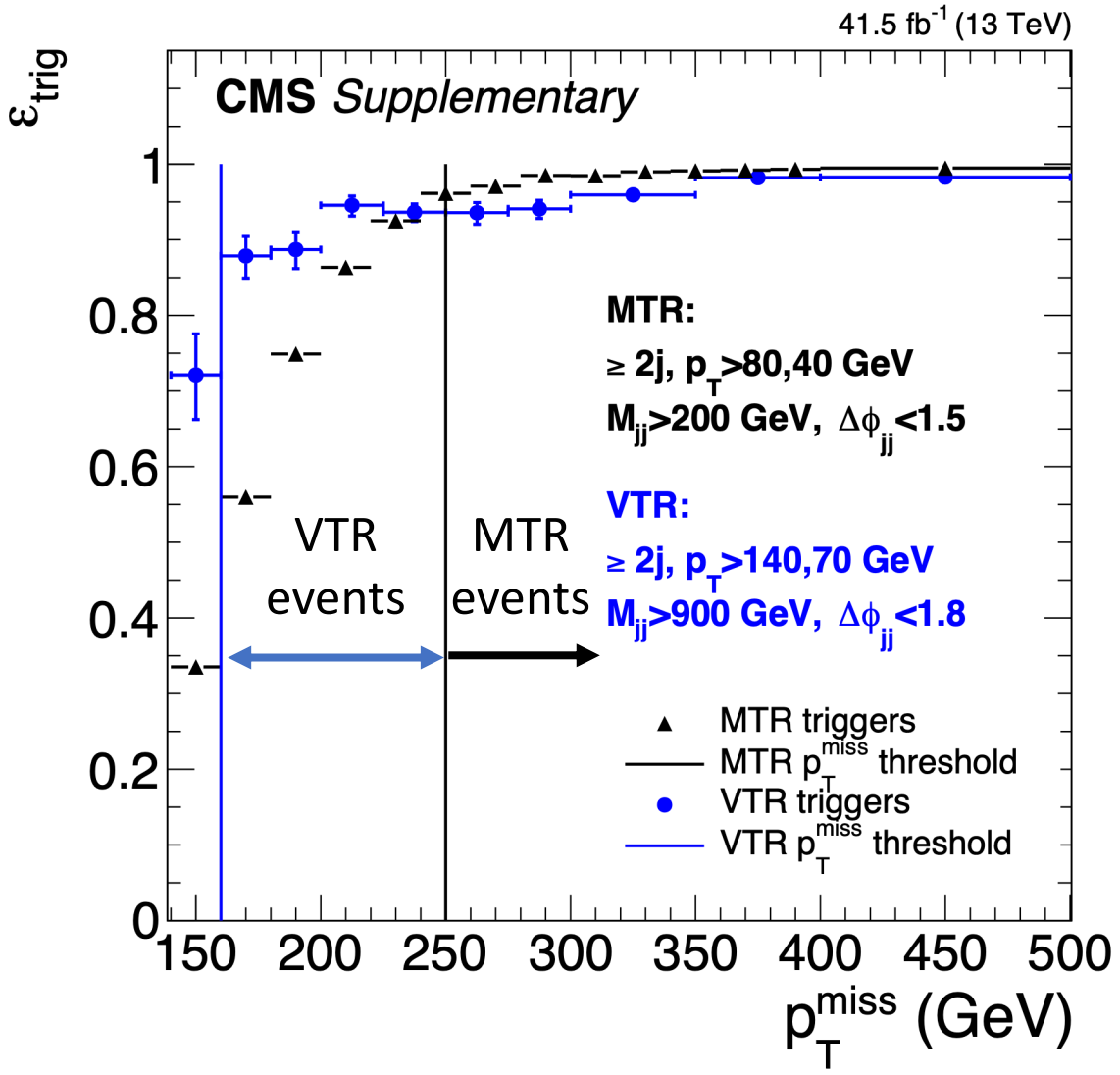


VBF H(inv)

CMS-PAS-HIG-20-003

VBF H(inv): Event Selection (Online)

CMS-PAS-HIG-20-003



Two sets of triggers are used for two data taking categories:

- **MTR:** p_T^{miss} triggered category, target $p_T^{miss} > 250\ GeV$
- **VTR (new in 17+18):** VBF triggered category, target events @ lower p_T^{miss}

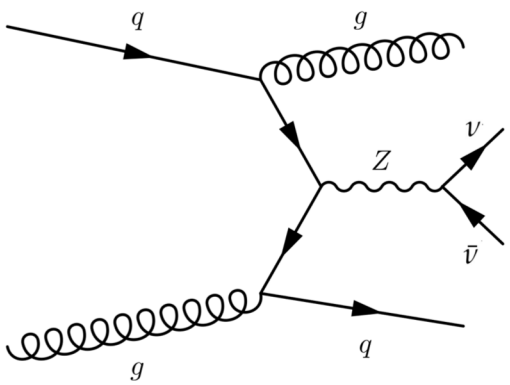
→ VTR improves the sensitivity by $\approx 8\%$

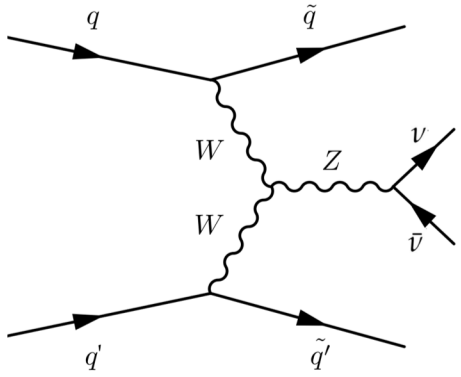
VBF H(inv): Strategy

CMS-PAS-HIG-20-003

Dominating backgrounds in VBF signal region:

$V + 2\ jets$





$QCD\ V + jets$

$\sigma \sim \alpha_s^2 \alpha_{EW}^2$

Larger XS

$EWK\ V + jets$

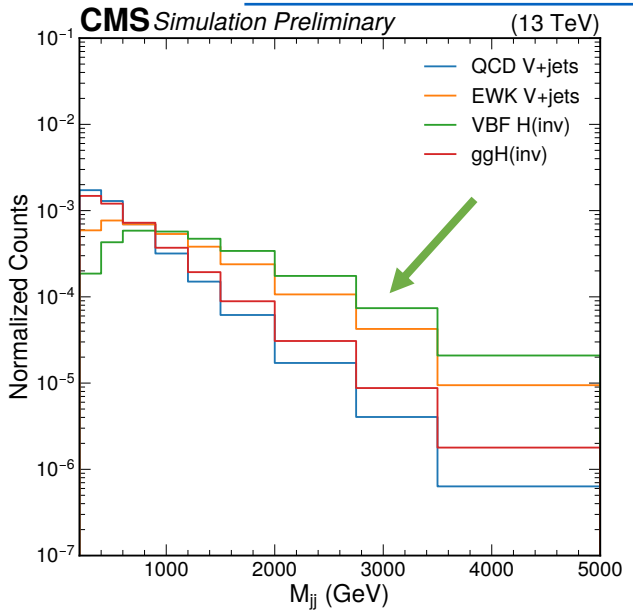
$\sigma \sim \alpha_{EW}^4$

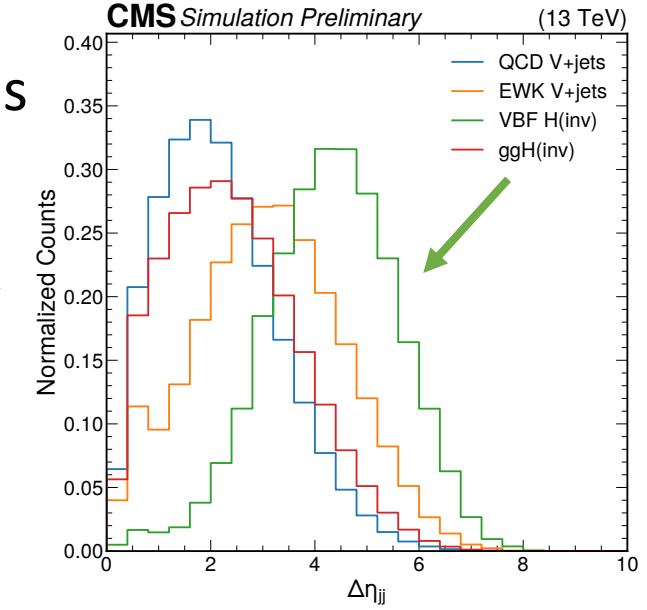
Important contribution @ high m_{jj}

VBF signal

vs.

$V + jets$ backgrounds



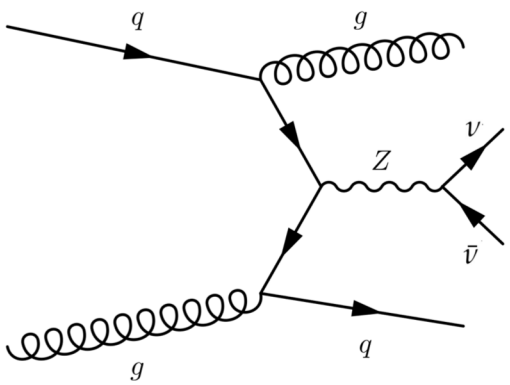


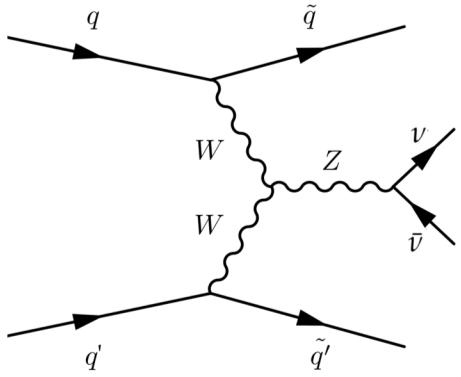
VBF H(inv): Strategy

CMS-PAS-HIG-20-003

Dominating backgrounds in VBF signal region:

$V + 2\,jets$





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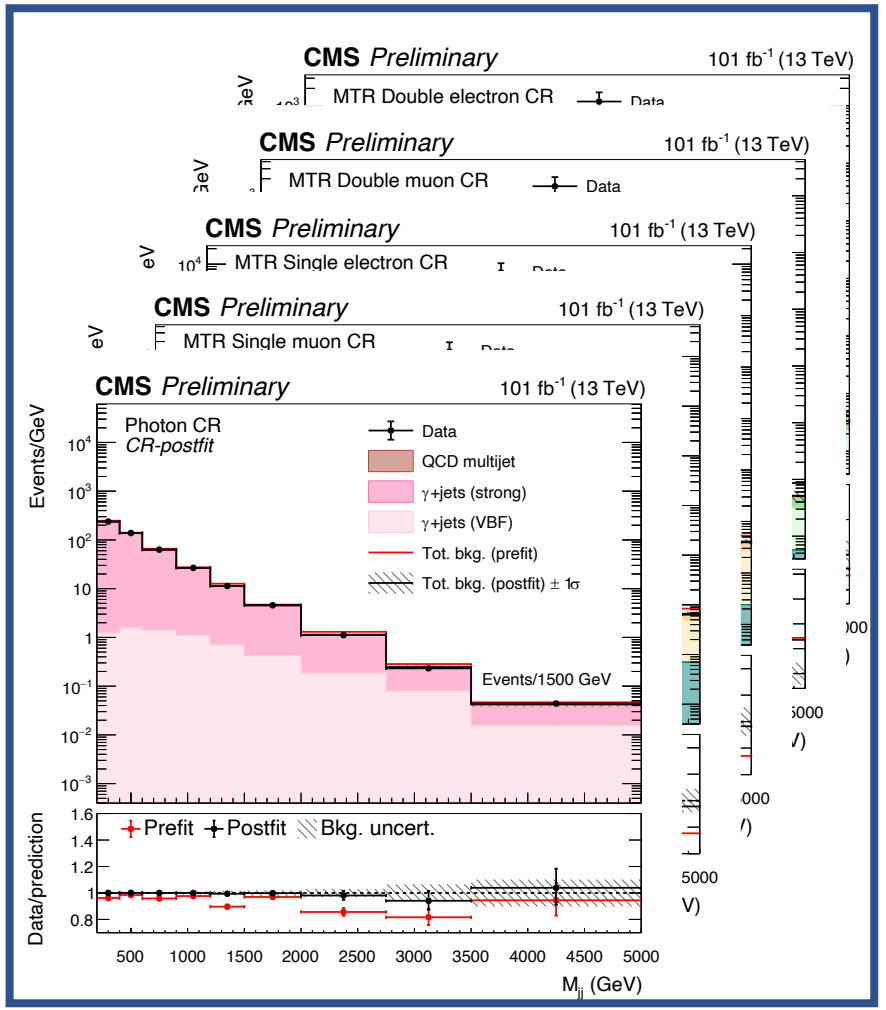
Important contribution @ high m_{jj}

Bkg. estimation with CRs

Dedicated control regions to estimate $Z(\nu\nu), W(\ell\nu)$ backgrounds in signal region:

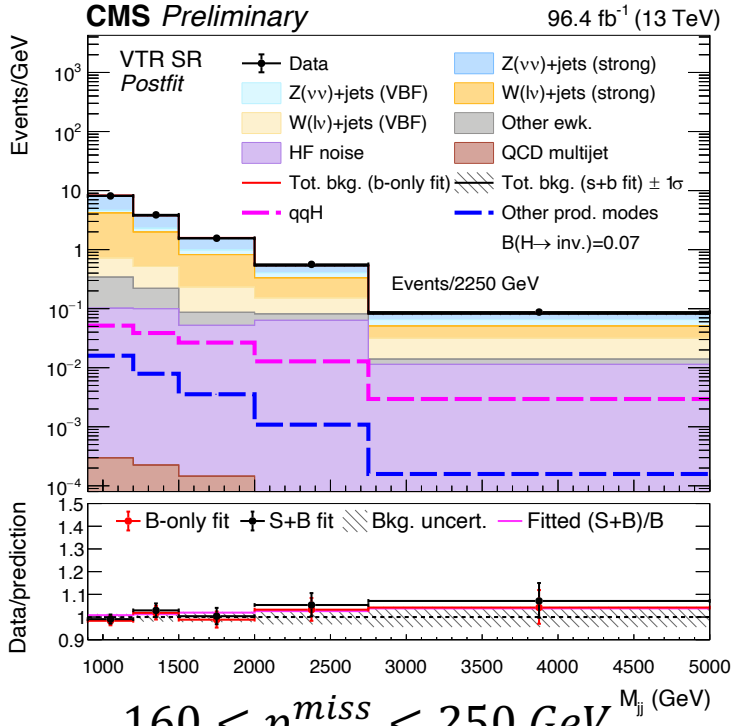


VBF H(inv): Data vs Bkg. Predictions

CMS-PAS-HIG-20-003

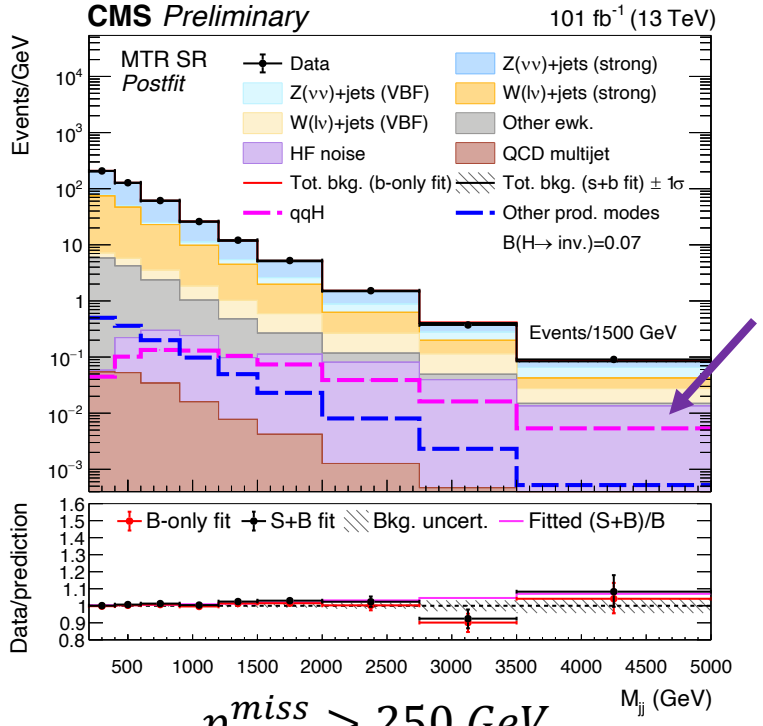
Data & background estimation in signal region:

VTR 2017+2018:



$160 < p_T^{miss} < 250\ GeV$

MTR 2017+2018:



$p_T^{miss} > 250\ GeV$

HF Noise: New HF noise estimate in 17+18

See the VBF talk by **Nicholas Wardle**

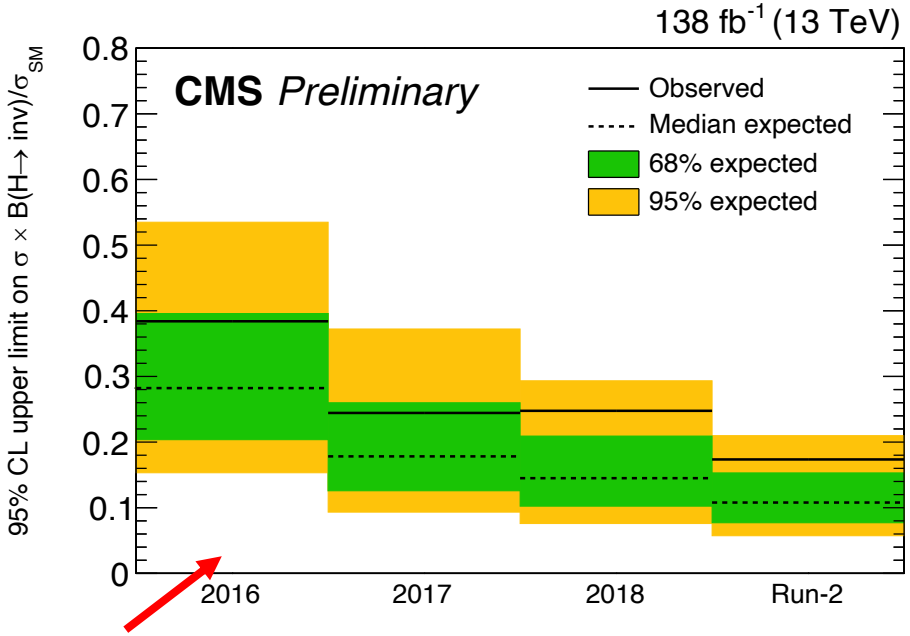
No excess of data over background predictions are observed in either category

→ Put constraints on $B(H \to inv)$

VBF H(inv): Results

CMS-PAS-HIG-20-003

Exclusion limits on $B(H \rightarrow inv)$:



2016: Taken from HIG-17-023

Statistical combination with HIG-17-023:

Expected sensitivity: **11%**, observed: **17%**

→ Best single-channel sensitivity to date!

VBF H(inv): Results

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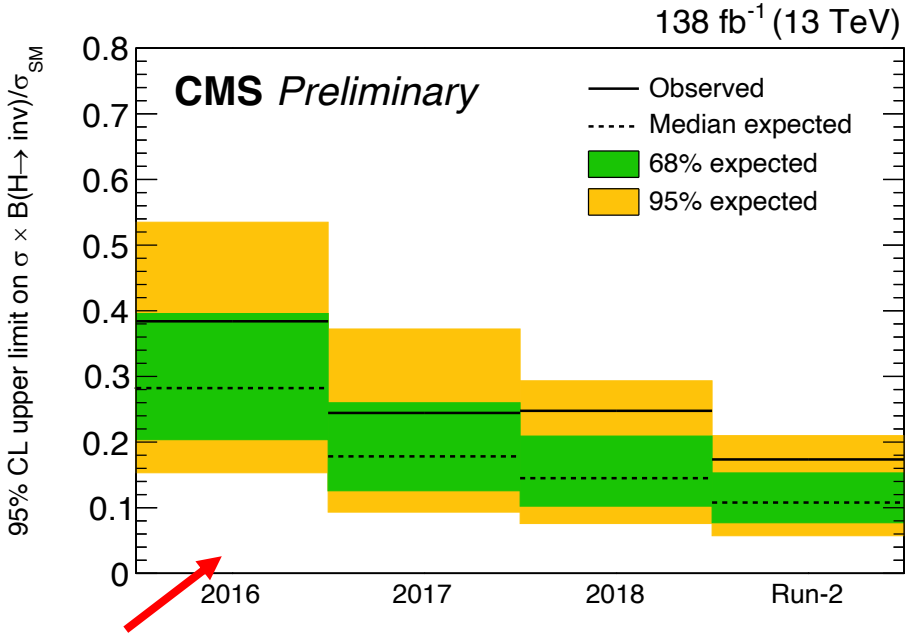

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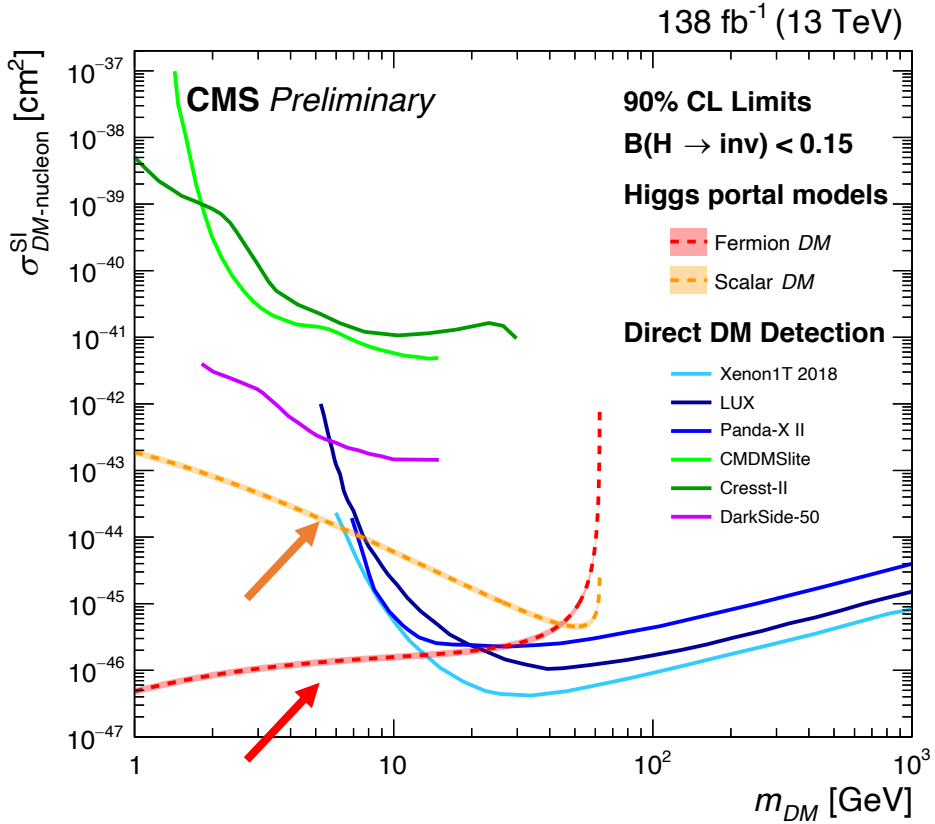
CMS-PAS-HIG-20-003

DM Interpretation

Can compare the results with direct detection:

Exclusion on $B(H \rightarrow inv)$ → Exclusion on σ_{DM}



→ Results complement the direct-detection experiments nicely for $m_{DM} < O(10\ GeV)$

Summary

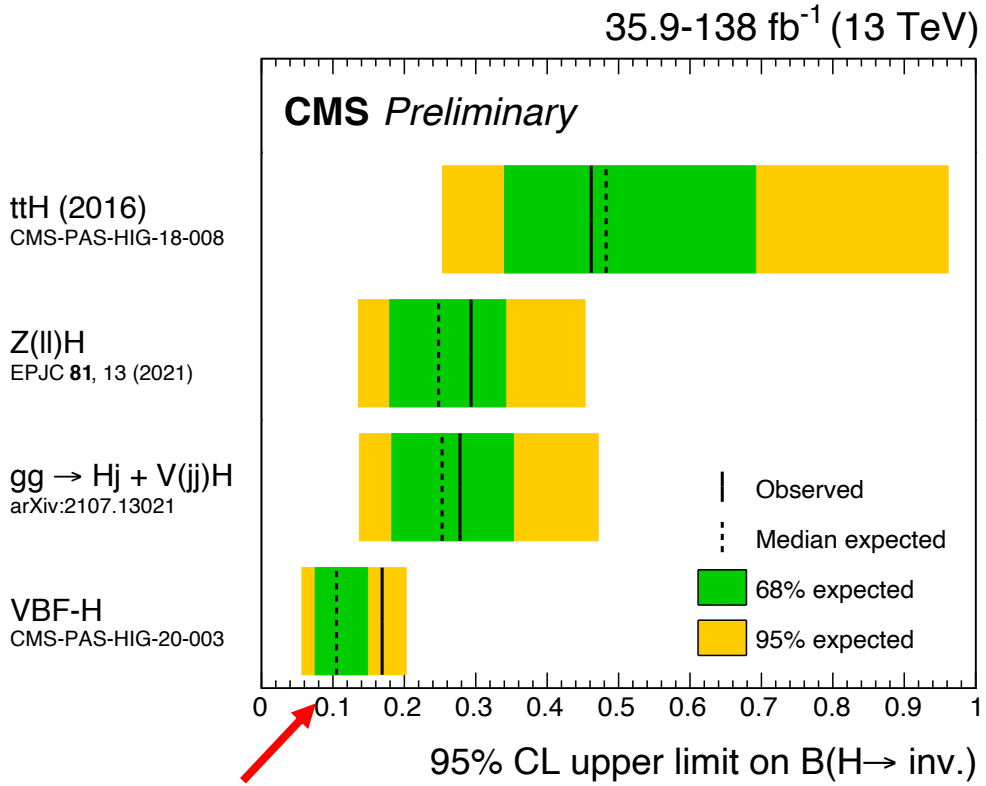
An overview of the H(inv) searches from CMS through different channels:

- ✓ VBF, monojet + mono-V, mono-Z

Improvements with full Run2 data for all channels:

- ✓ Obs. (exp.) exclusion limit reaches to 17% (11%) with VBF

Exclusion limits from different channels:



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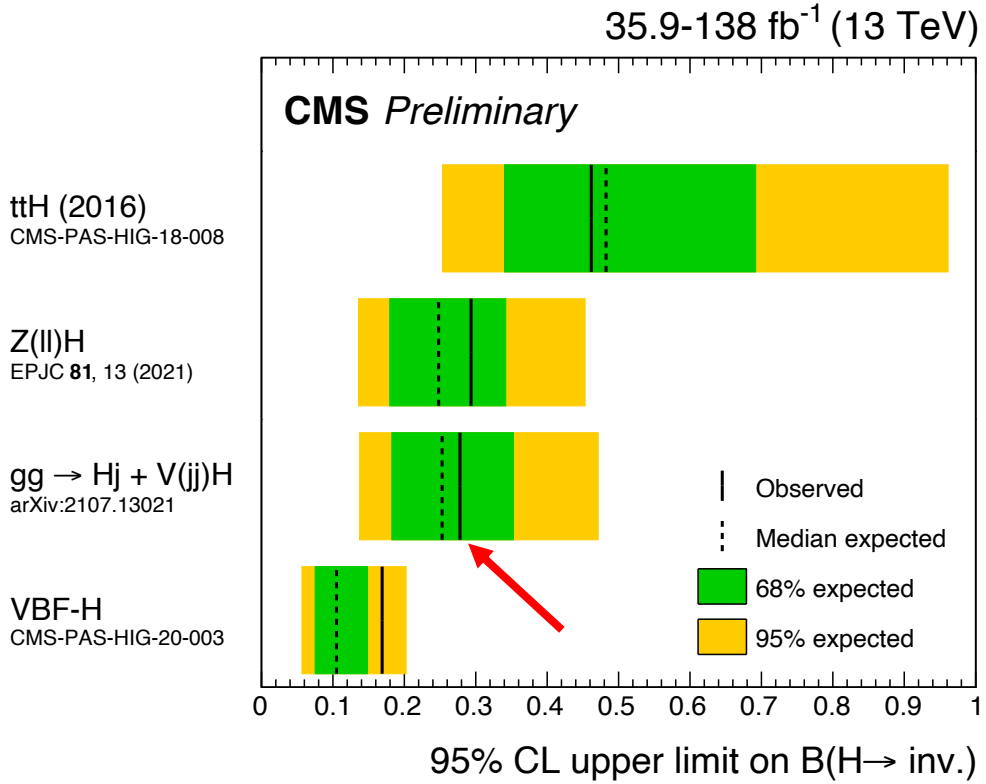

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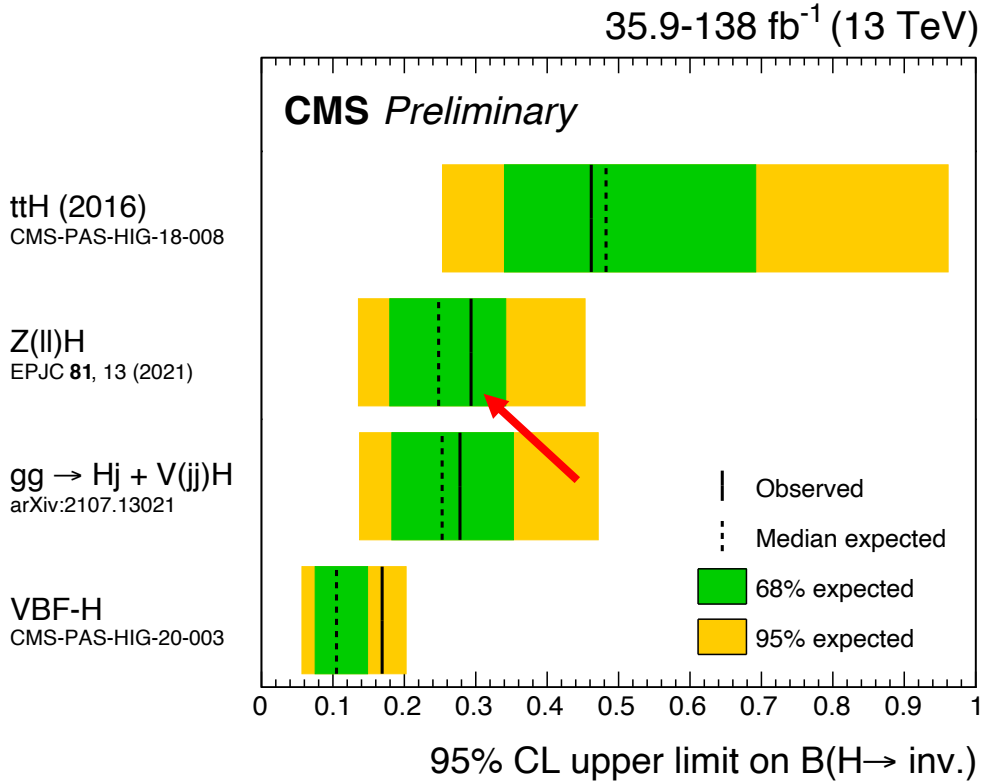
- ✓ **Monojet + mono-V** → $1.9x$ improvement in obs. limits, 28% observed limit
- ✓ **Mono-Z** → $1.7x$ improvement from previous CMS results, 29% observed limit

ttH & combinations → Ongoing

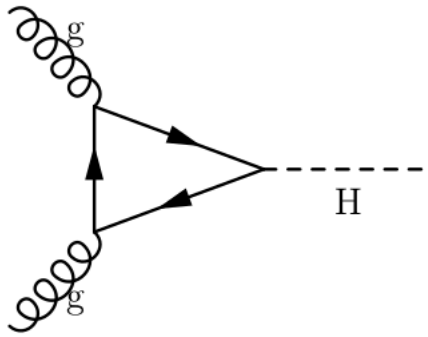
Exclusion limits from different channels:



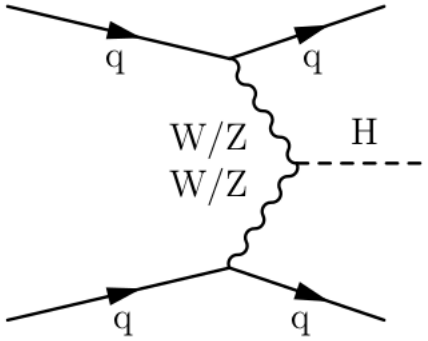
Backup

Higgs Production Modes: XS

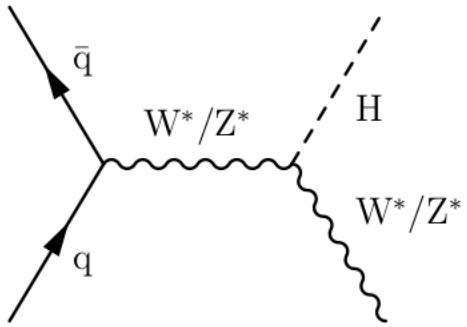
Order of magnitude XS for the H production modes:



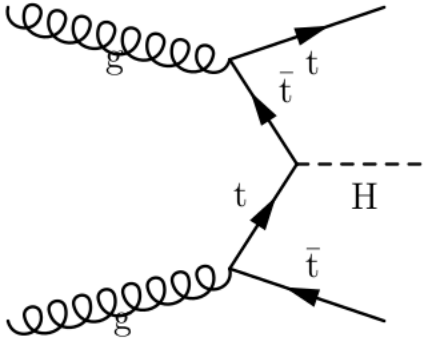
(a) Gluon Fusion



(b) Vector Boson Fusion



(c) Associated Production W/Z



(d) Associated Heavy Quark Production

Gluon fusion
→ Largest XS
compared to all
$\sigma_{ggH} \approx 10 \times \sigma_{VBF}$

Second largest XS
after gluon fusion
$\sigma_{VBF} \approx 4\,pb$

$\sigma_{VH} \sim O(1\,pb)$

$\sigma_{ttH} \sim O(1\,pb)$

Largest XS: ggH

Highest sensitivity: VBF due to specific topology

VBF: Updates From 2016 Analysis

Updates from HIG-17-023 in the 2017+2018 VBF analysis:

✓ Addition of photon CR

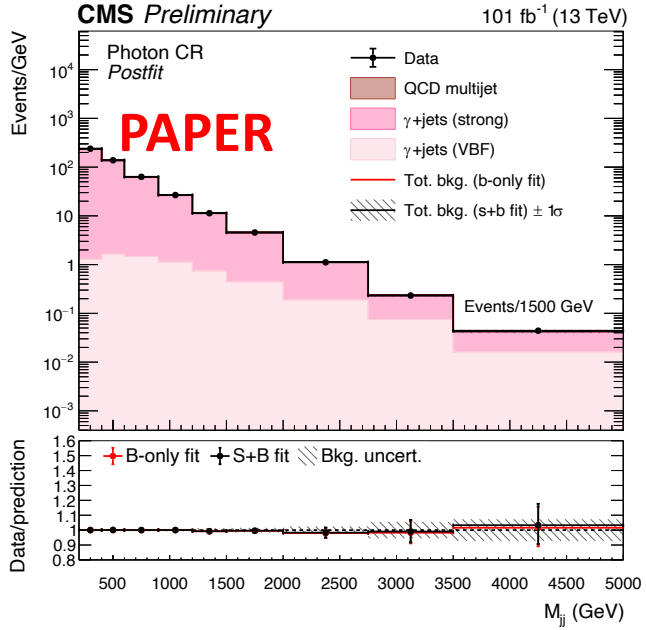
✓ Inclusion of VBF triggered category (**VTR**) for $p_T^{miss}\ \epsilon\ [160{,}250]\ GeV$

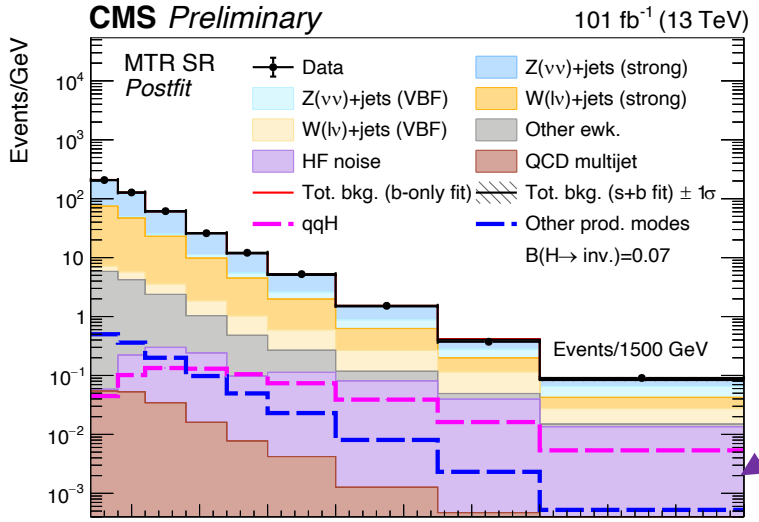
→ In addition to the MET+MHT triggered category (**MTR**)

✓ Addition of HF cleaning cuts

→ The first time we had access to **HF-HF events!**

✓ NLO EWK correction on VBF H(inv) signal

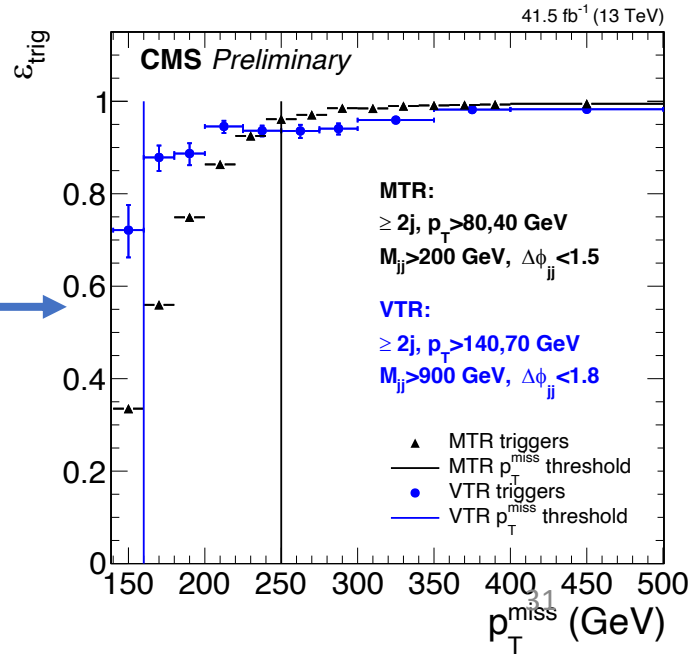




HF noise estimate in SR

Trigger efficiencies as a function of MET for MTR & VTR

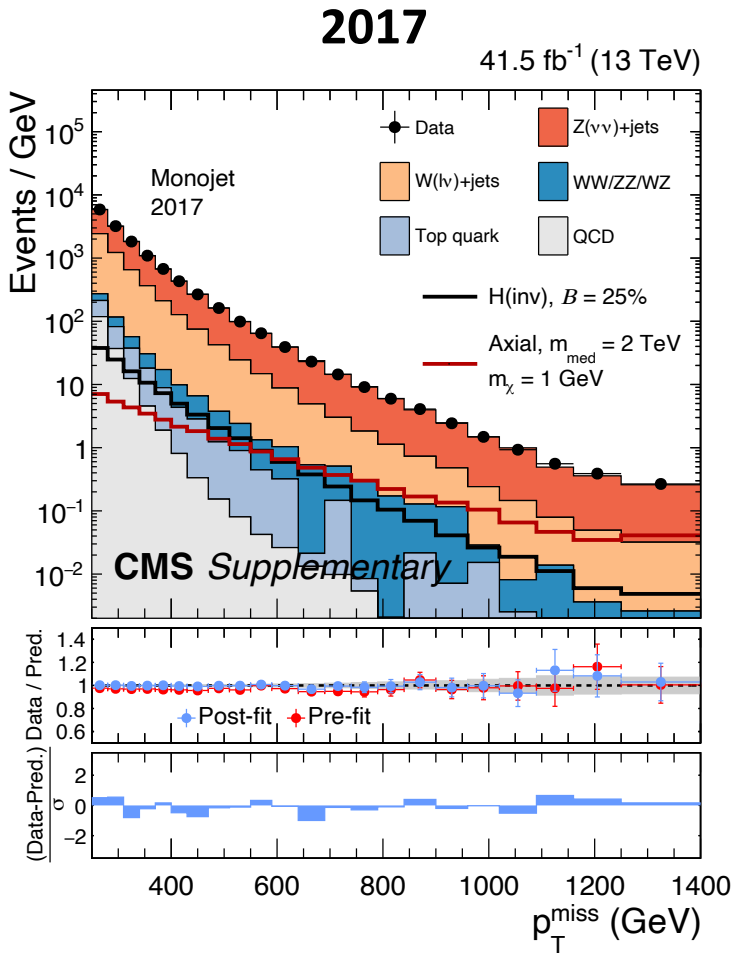
→ Higher efficiency from lower p_T^{miss} with VBF triggers

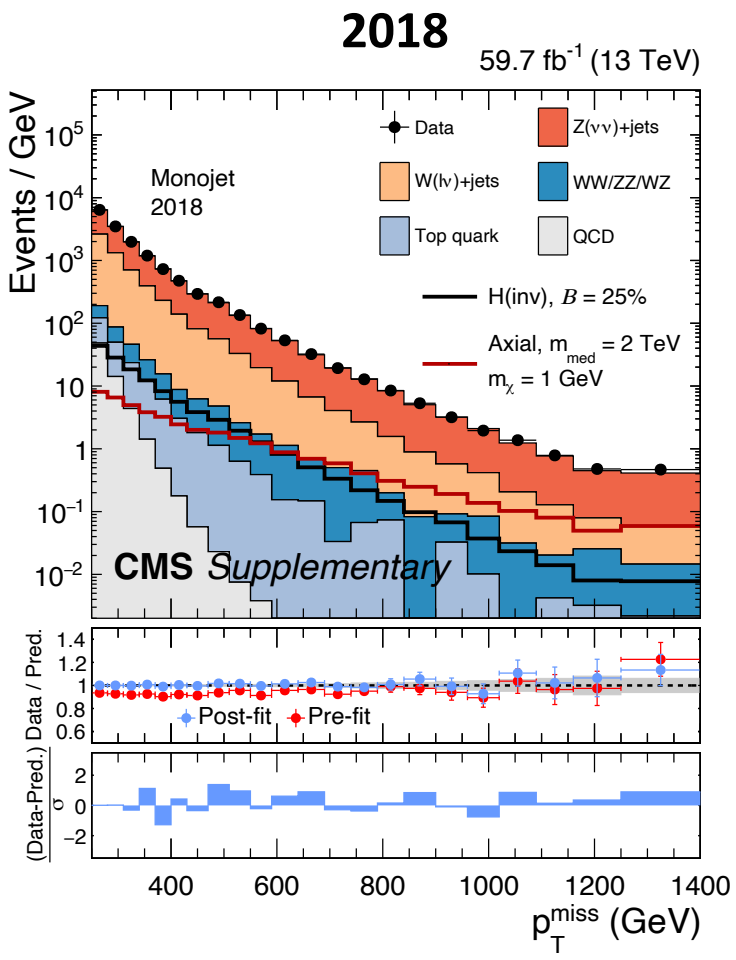


Monojet: Year Separated Results

arXiv:2107.13021

Monojet signal region, shown with 2017 and 2018 data separately:

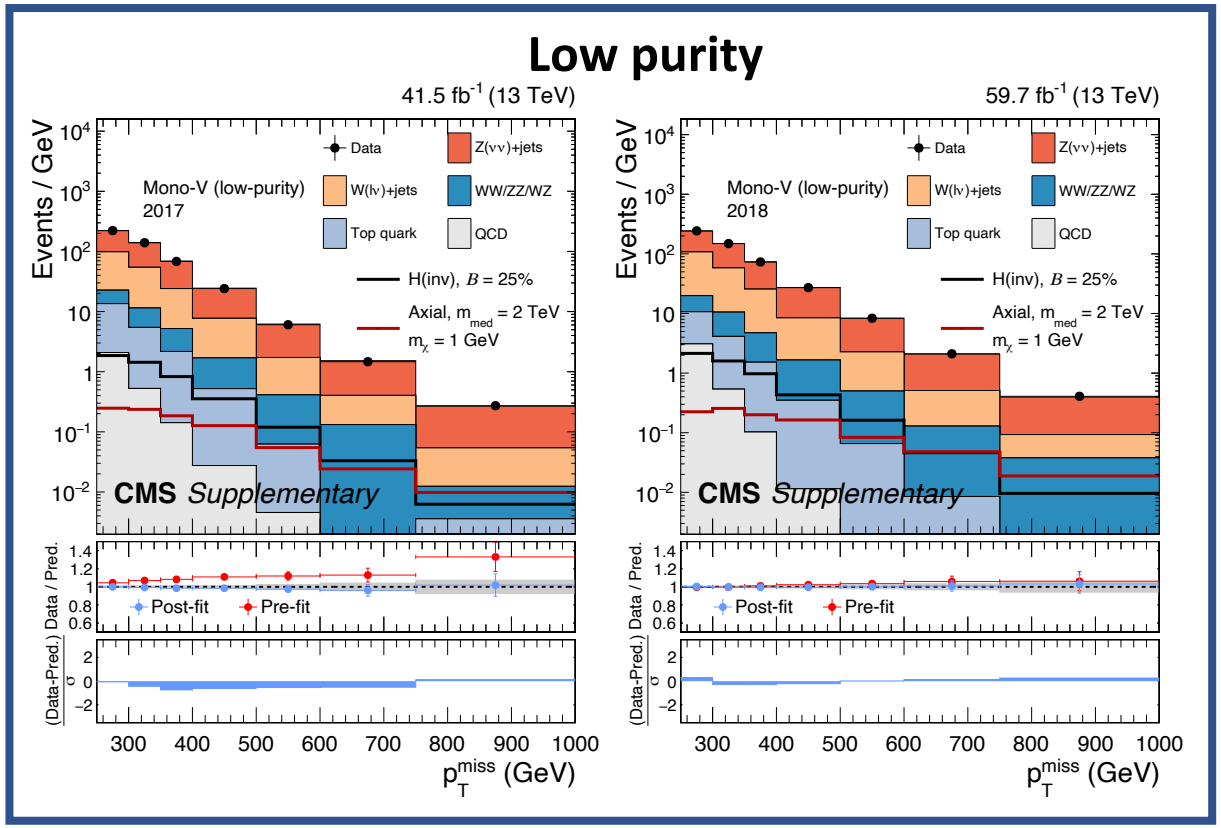


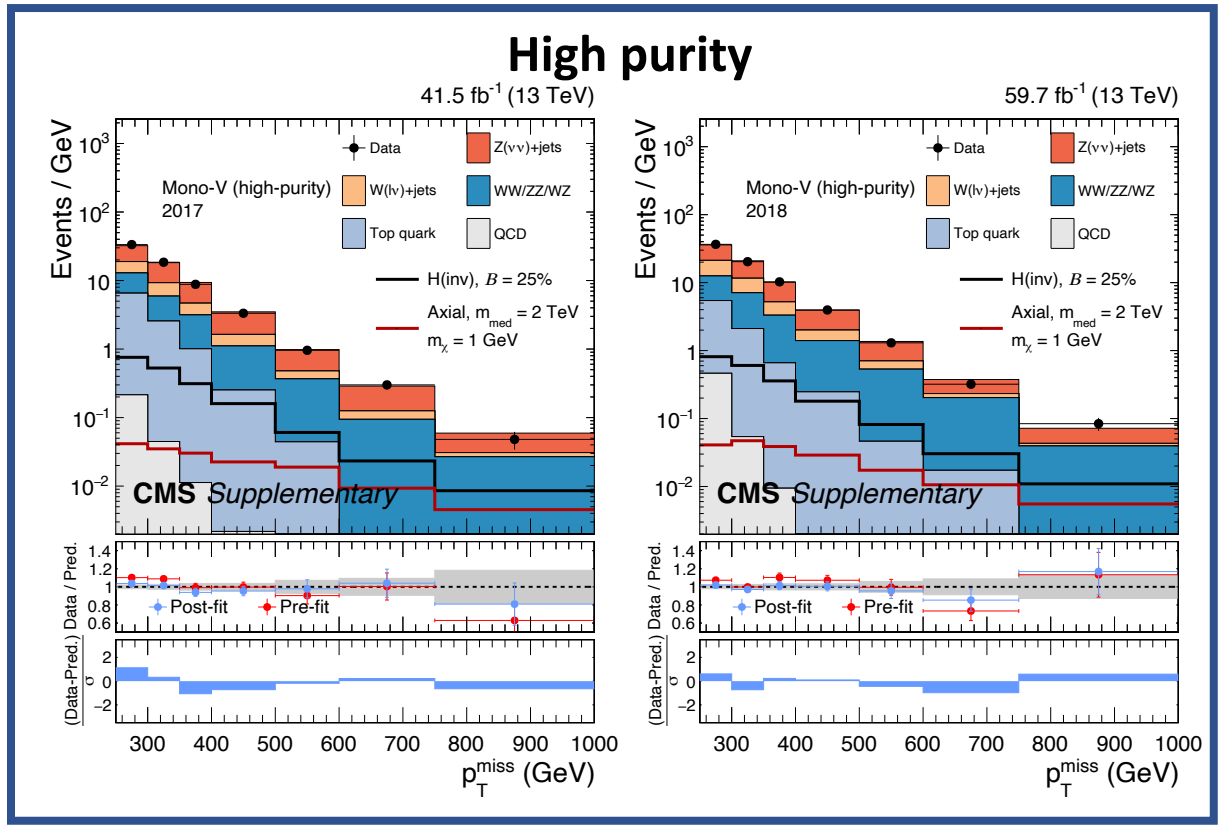


Mono-V: All Results

arXiv:2107.13021

Mono-V results in signal region for both low and high purity categories:





Good agreement between data and bkg predictions after the fit

Mono-Z: 0-jet & 1-jet Categories

Eur. Phys. J. C (2021) 81:13

Event yields in the two categories of the mono-Z signal region:

Table 3 Observed number of events and post-fit background estimates in the two jet multiplicity categories of the SR. The reported uncertainty represents the sum in quadrature of the statistical and systematic components

Process	0-jet category	1-jet category
Drell–Yan	502 ± 94	1179 ± 64
WZ	1479 ± 53	389 ± 16
ZZ	670 ± 27	282 ± 13
Nonresonant background	384 ± 31	263 ± 22
Other background	6.3 ± 0.7	6.8 ± 0.8
Total background	3040 ± 110	2120 ± 76
Data	3053	2142

Post-fit yields + total post-fit uncertainties on the backgrounds

0-jet category: Larger contribution from diboson processes

1-jet category: Larger contribution from DY

→ Overall, larger # of background events from 0-jet category