Searches for Higgs to invisible: status and plans

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On behalf of the CMS Collaboration

May 2024

Theory motivation

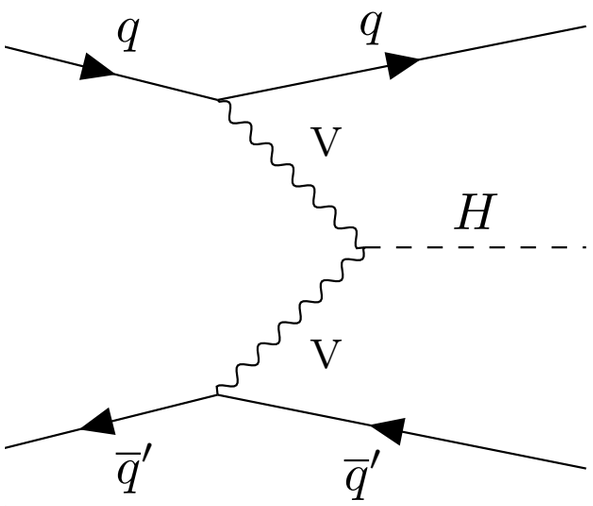
- Higgs to invisible
  - Branching fraction ($\mathscr{B}$) in the SM $\sim \mathcal{O}(0.1\%)$
  - Detectors resolution and available statistics at the LHC insufficient to probe it

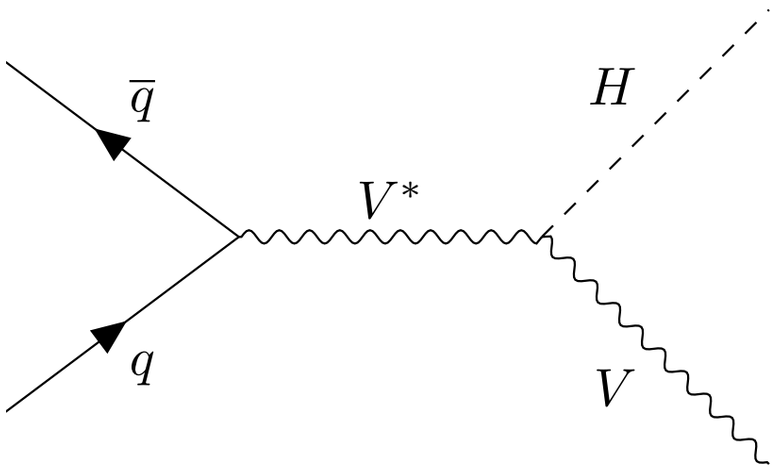
- BSM scenarios predicts higher $\mathscr{B}$
  - Portals models: mediators between SM and DM candidates
  - Dark photon, scalar mediators, Higgs portal, ...

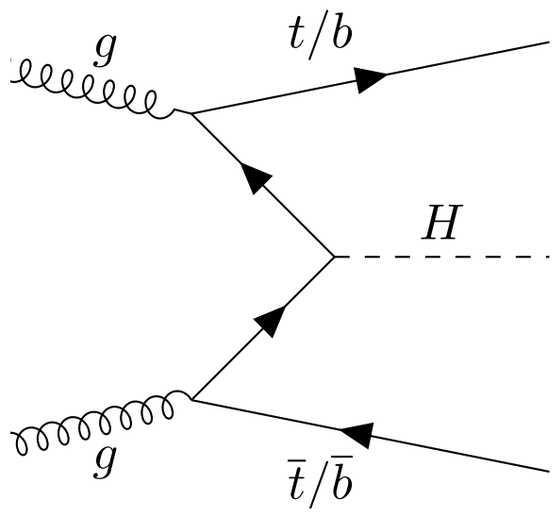
- Focus of this talk:
  - Searches in CMS
  - Upper limits on SM $\mathscr{B}$
  - Higgs portal interpretations

Main search channels

- Vector Boson Fusion (VBF)
  - Primary sensitivity, background suppression with two tagging jets
- Higgs-Strahlung (VH or Mono-V)
  - Second leading channel, clean selection from vector boson identification
- top associated production (ttH)
  - Small cross-section, statistically limited
- gluon-gluon fusion (ggH or Monojet)
  - Large cross-section, but large QCD background







Overview of past CMS results

Run 1

Run 2

Run 3

2016
VBF + VH + ggH
$\mathcal{B}$<0.24(0.23)

2014
VBF +VH
$\mathcal{B}$ < 0.58 (0.44)

2021
Mono+X
$\mathcal{B}$ < 0.28 (0.25)

2022
VBF combination
$\mathcal{B}$ < 0.18(0.10)

2023
Legacy comb.
$\mathcal{B}$ < 0.15 (0.08)

?

VBF channel

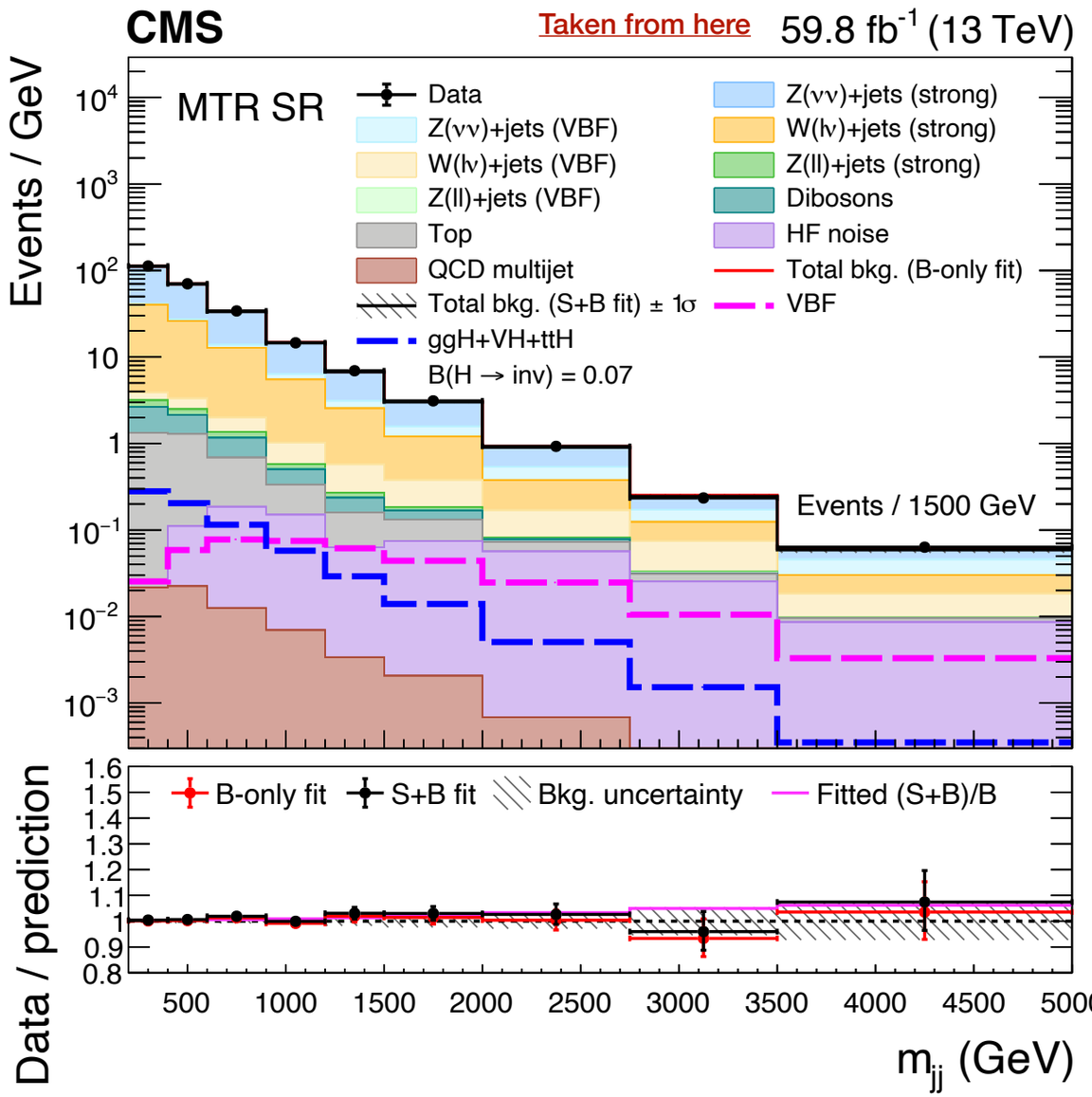
Analysis in a nutshell

- Online selections
  - MET triggers (MTR) as the primary category
  - VBF trigger (VTR) selections as additional category
- Offline selections:
  - MET > 200 GeV
  - 2 well-separated forward jets
- Final discriminant:
  - forward jet invariant mass (m_{jj})
  - VBF production dominates at high m_{jj}

  ($\sim 50\,\%$ for $m_{jj} > 3.5$ TeV)

Most sensitive production mode

- Second highest cross section
- Clean signature from 2 forward jets



VH channel

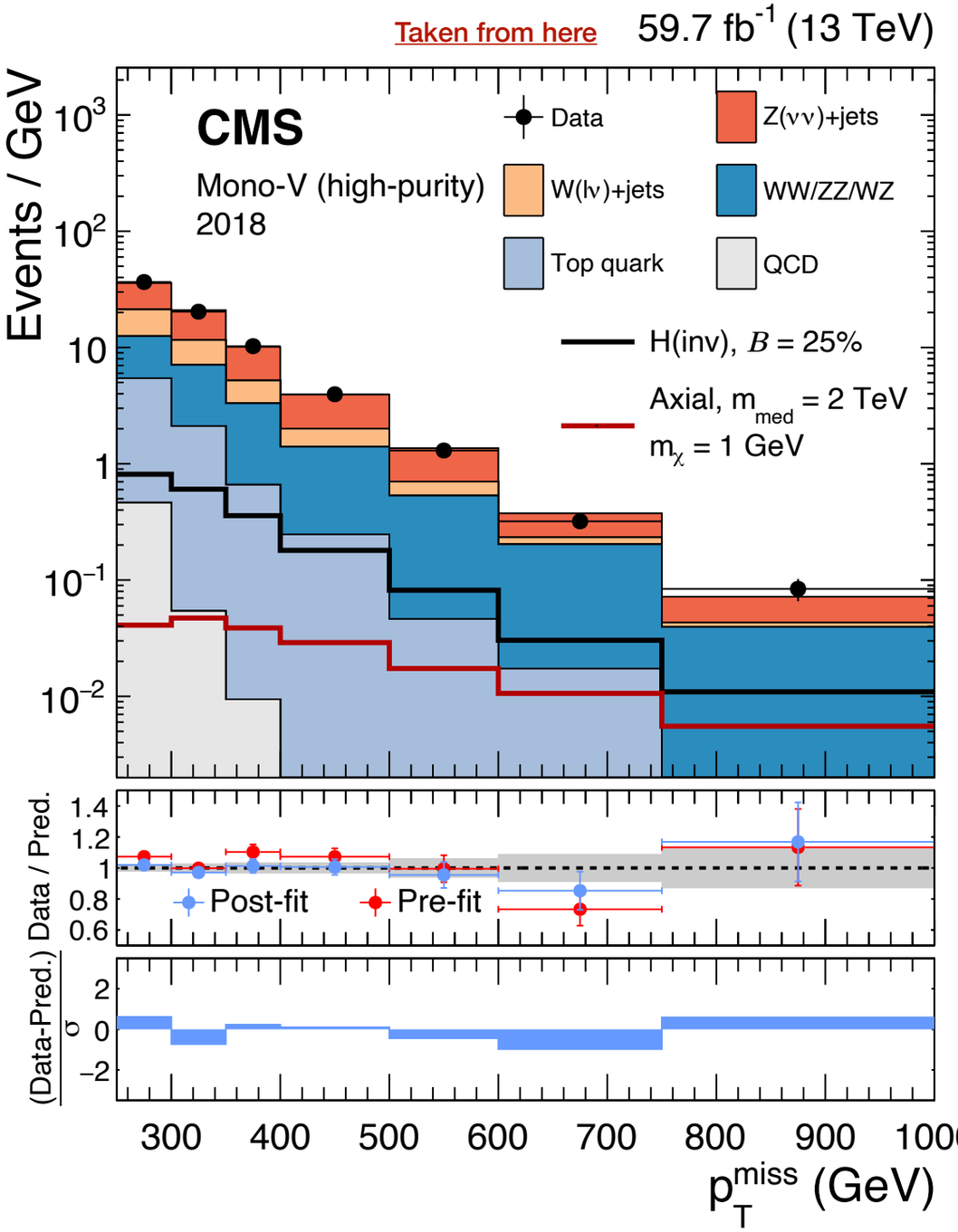
Different categories explored

- $Z \to \ell\ell$
- $Z \to qq$ merged
- $Z \to qq$ resolved

Analysis in a nutshell

- $Z \to \ell\ell$
  - Balance between MET and $p_T(\ell\ell)$
- $Z \to qq$ merged:
  - V-tagging with ML
- $Z \to qq$ resolved:
  - Complementary to $Z \to qq$ "merged" and ttH
- Final discriminant:
  - MET

Taken from here



ttH channel

Different categories explored

- N. reconstructed top
- N. reconstructed W
- B-tag and jet multiplicity

Final discriminant

- MET

Analysis in a nutshell

- ttH (hadronic)
  - Challenging background
  - Optimised to balance event quality and signal purity
  - Orthogonality with other channels
- ttH (leptonic)
  - Re-interpretation from SUSY searches (1L and 2L)

Category	Subcategory	n_j	n_b	n_t	n_W
Boosted $t\bar{t}H$	2Boosted1b	≥ 5	1	2	
	2Boosted2b	≥ 5	≥ 2	2	
	1t1b	≥ 5	1	1	0
	1t2b	≥ 5	≥ 2	1	0
	1W1b	≥ 5	1	0	1
	1W2b	≥ 5	≥ 2	0	1
Resolved $t\bar{t}H$	5j1b	5	1	0	0
	6j1b	≥ 6	1	0	0
	5j2b	5	≥ 2	0	0
	6j2b	≥ 6	≥ 2	0	0
VH	2j0b	2	0	0	0
	2j1b	2	1	0	0
	2j2b	2	2	0	0

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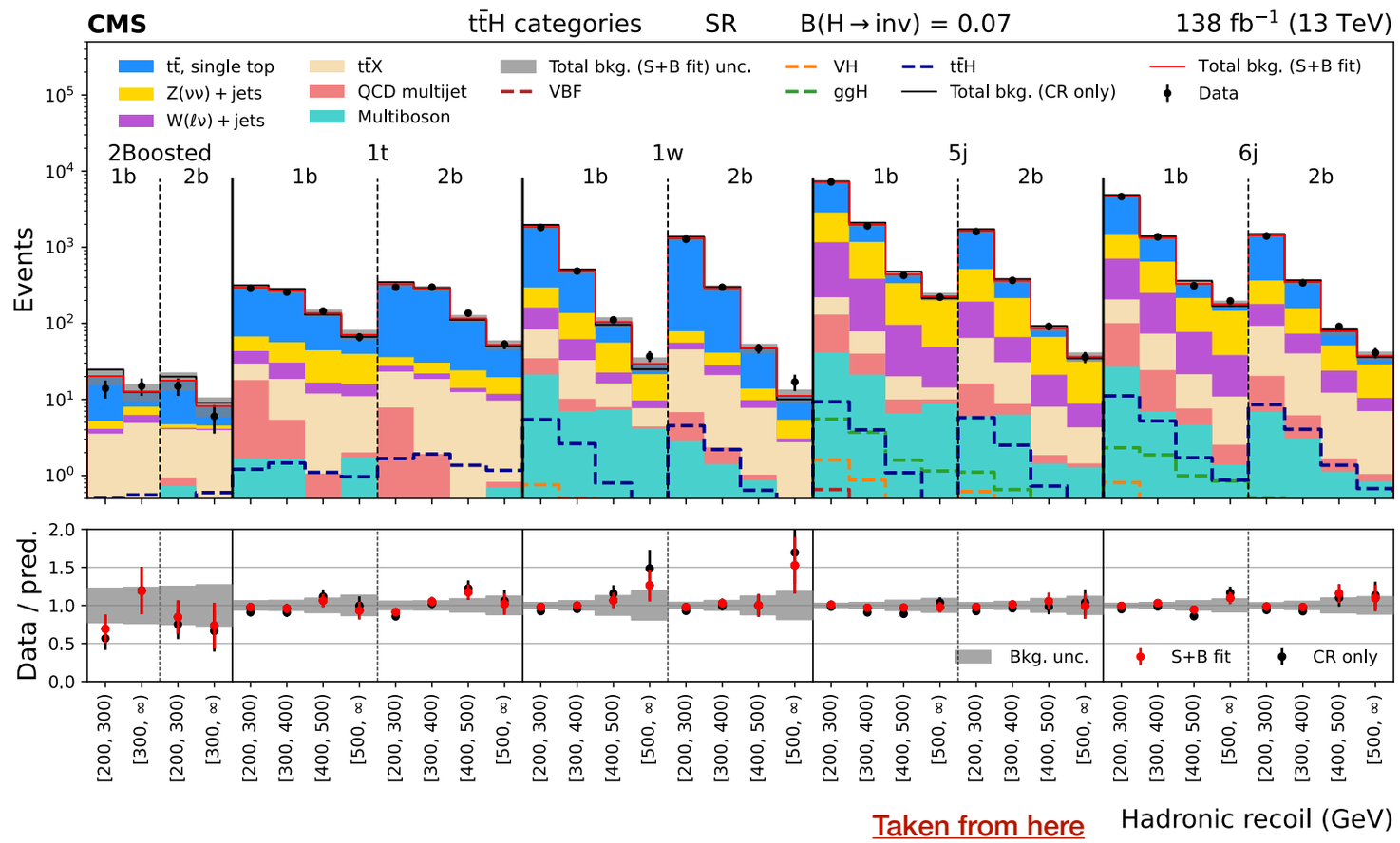

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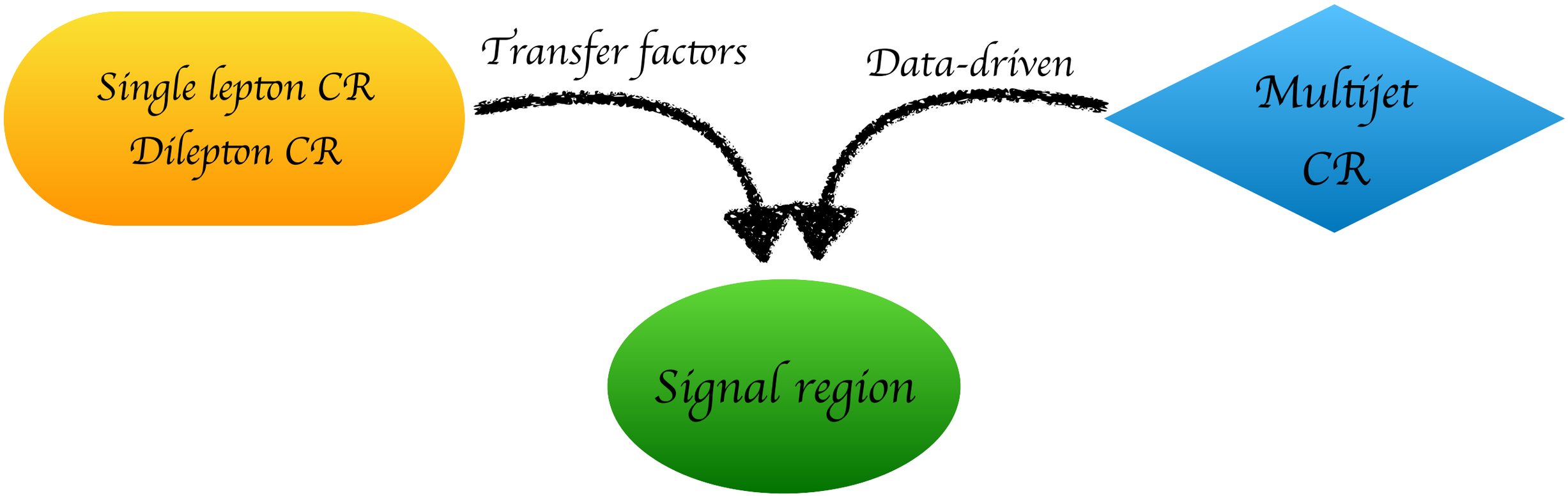
Experimental techniques

Control regions (CR)

- Used for precise prediction of background processes in SR
  - Real MET contributions ($Z \to \nu\nu$)
  - Fake MET due to lost leptons
- Constrain systematic uncertainties
  - Transfer factors
  - Data-driven estimations



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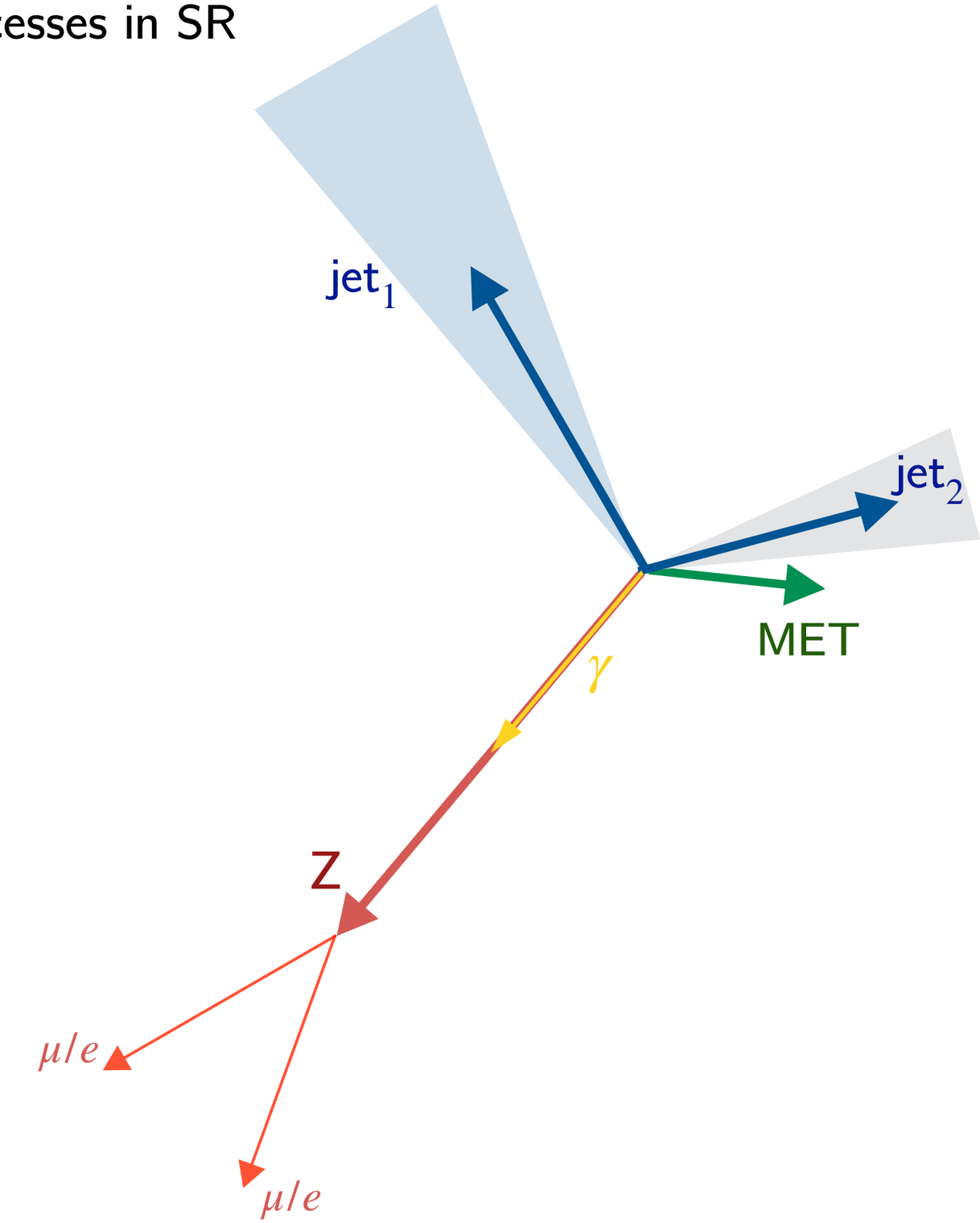
Hadronic recoil

- Equivalent to MET in Signal Region
- Good proxy of MET in Control Regions
  - Defined as MET + lepton/photon p_T



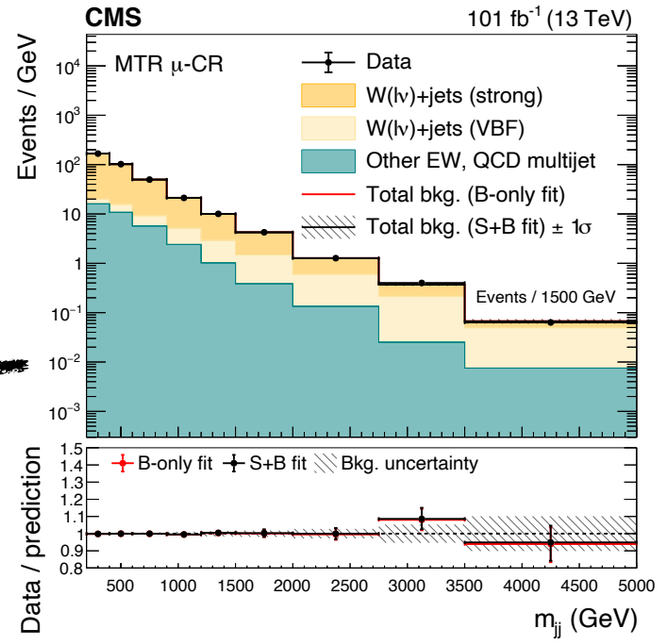
Experimental techniques

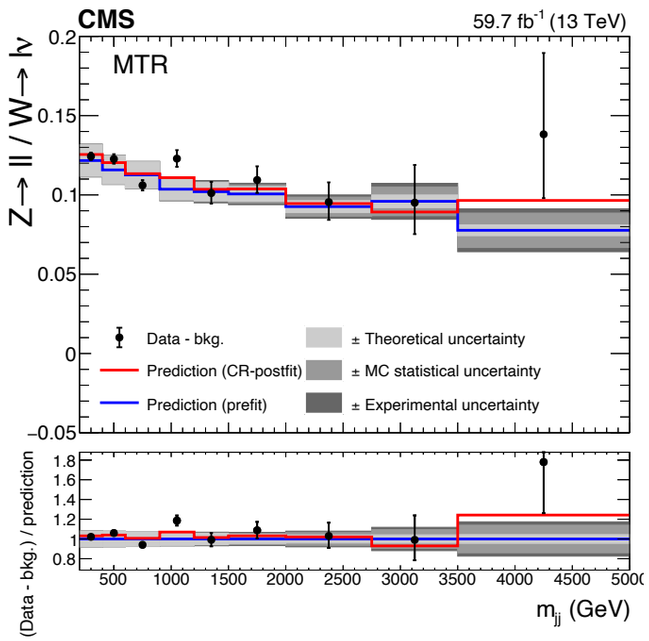
Taken from here

Primary sources of background

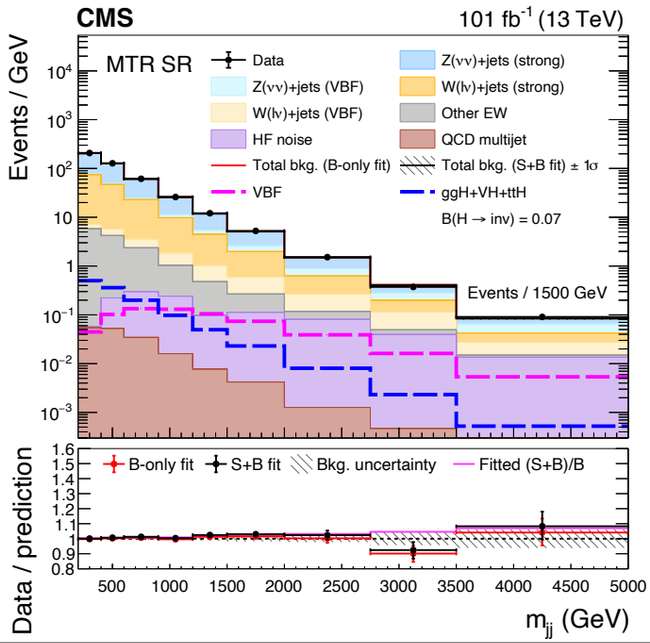
- Real MET contributions ($Z \to \nu\nu$)
  - Constrained from dilepton and single photon CRs
- Fake MET due to lost leptons ($t\bar{t}$ events, W + jets)
  - Constrained from single lepton CR

Transfer Factors





Constrain in Signal Region



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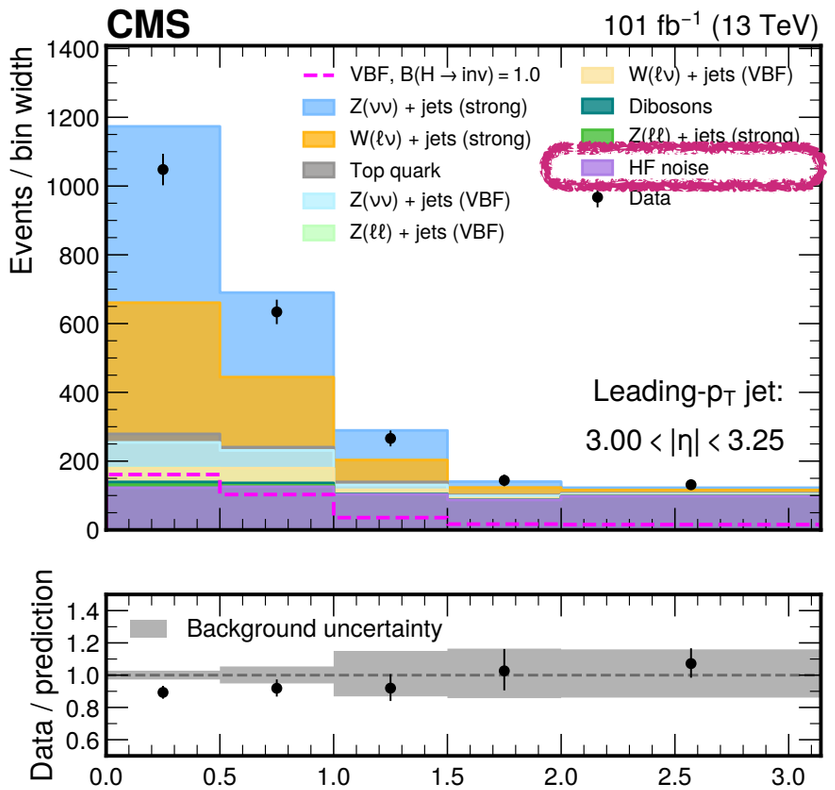
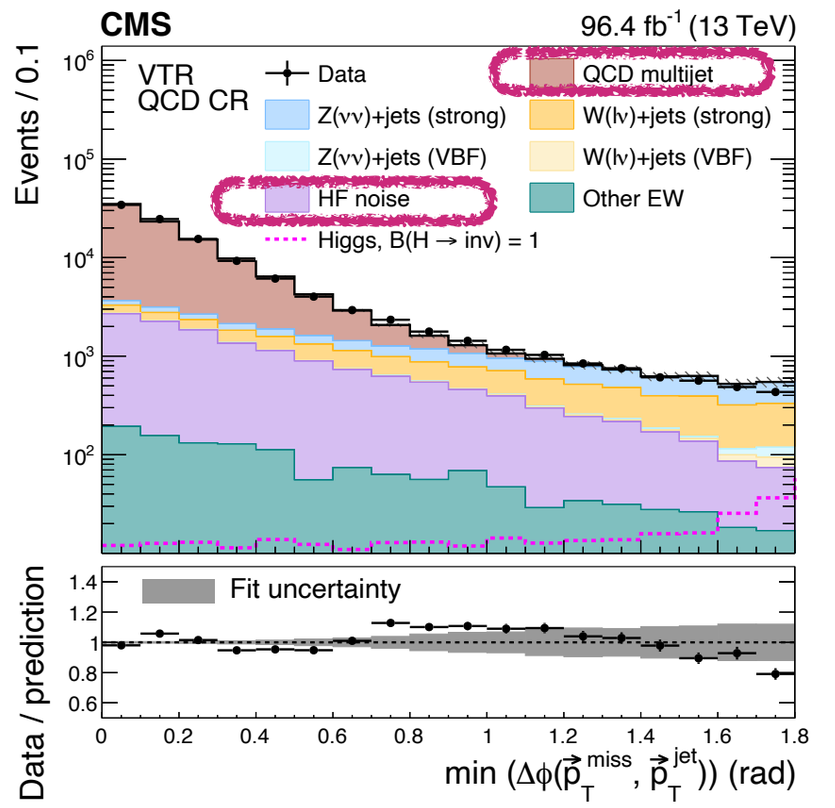


Other sources of background

- Jets miscalibration and detector noise
  - QCD multijet events
  - Data-driven estimation
- Minor contributions
  - Taken from simulation



Experimental techniques

Strategy

- Total or partial cancellations, thanks to transfer factors and control region
  - Cancel only when the same source is present in two control regions

Leading sources of uncertainties

- Statistical precision
  - $\sim 30\,\%$ in VBF cat.
  - Dominant source in ttH
- Photon identification
  - Up to $\sim 10\,\%$ due to limited statistics
- Jet energy scale/resolution
  - partially cancel, up to $\sim 10\,\%$
- Top/V/b-tagging
  - mostly in the ttH cat. $\sim 5 - 20\,\%$
- Theory $\sim 10 - 20\,\%$

Combination of Run1 + Run2

Sensitivity per channel

- Statistically dominated:
  - Combination with previous results significantly improves expected limits
  - Additional categories improve the sensitivity

List of all results

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Analysis tag	Production mode	Integrated luminosity (fb^{-1}) 7 TeV	8 TeV	13 TeV (Run 2)
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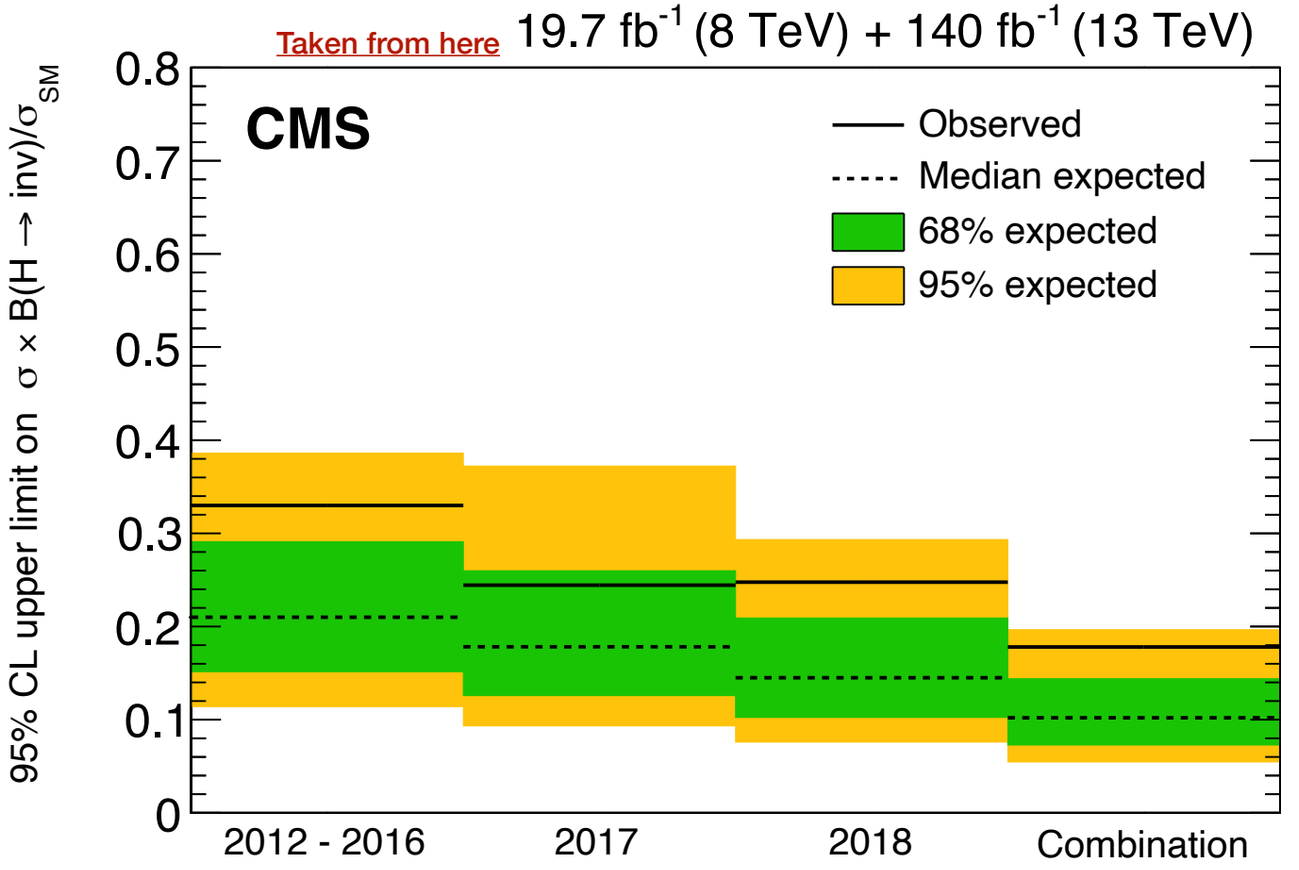

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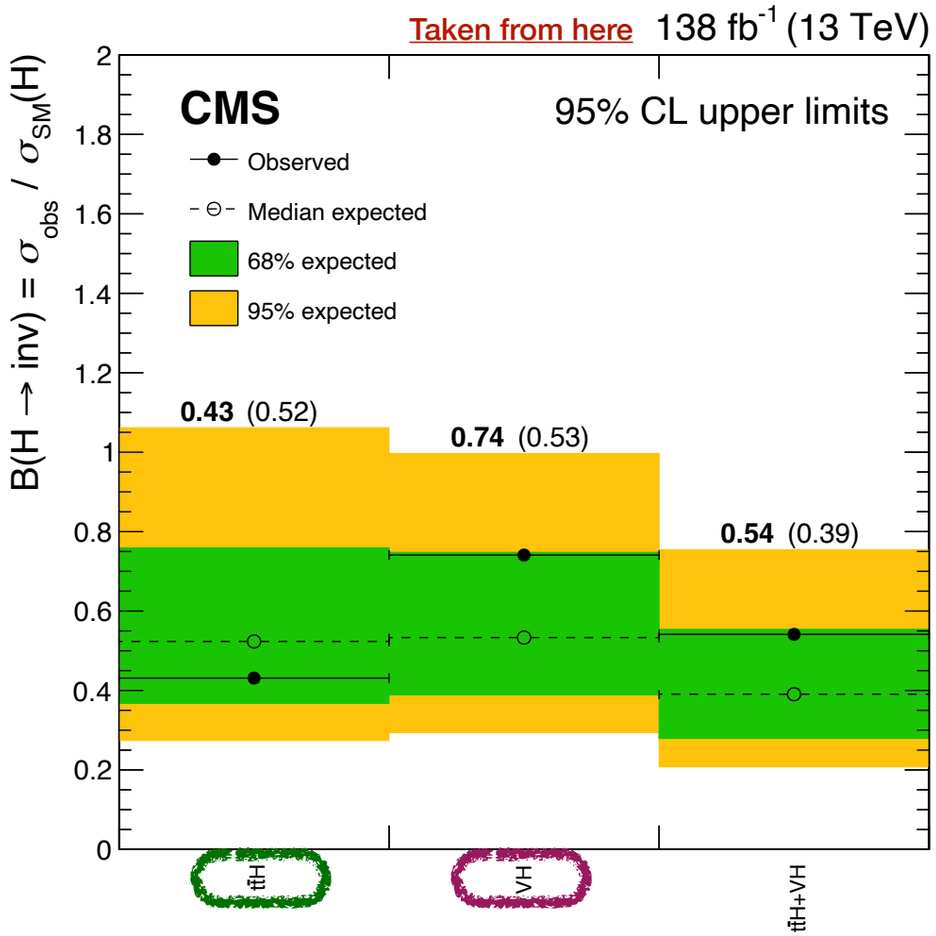

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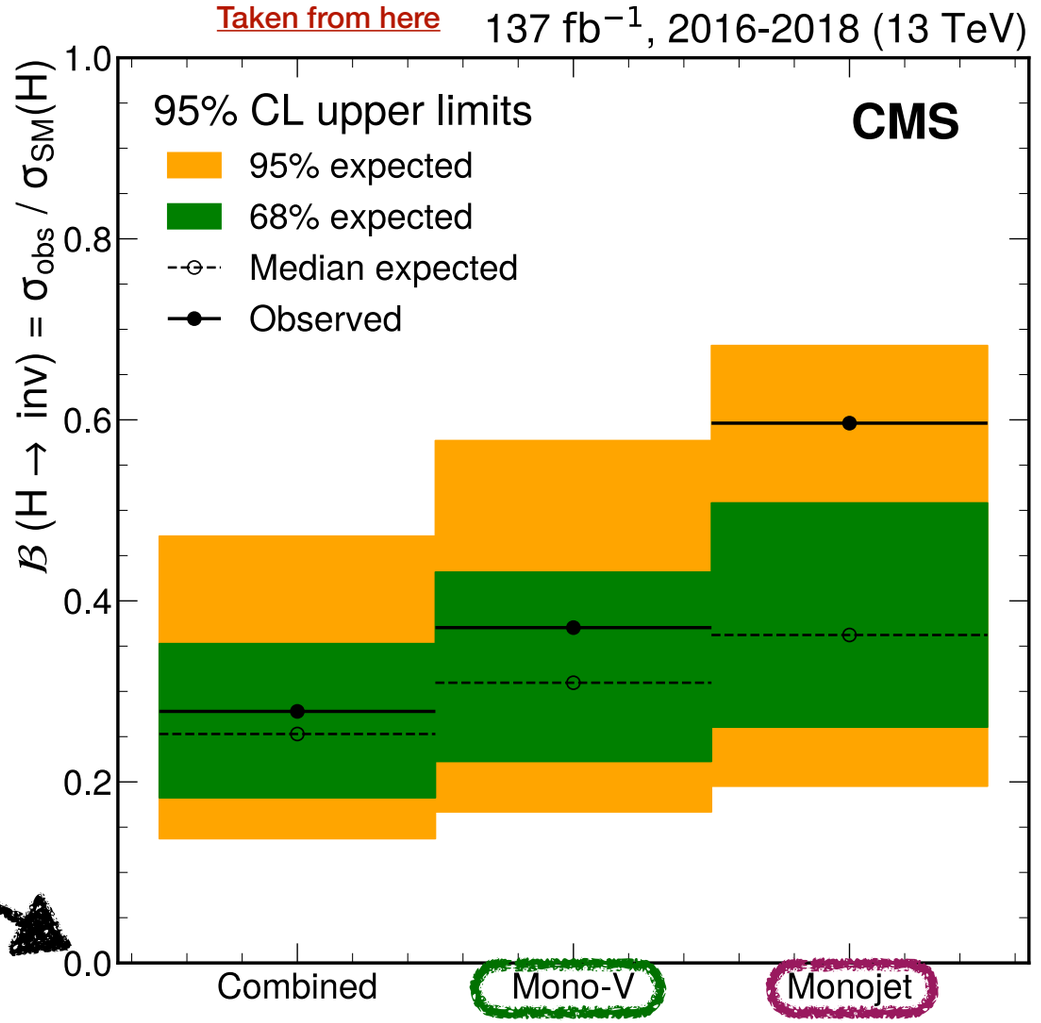

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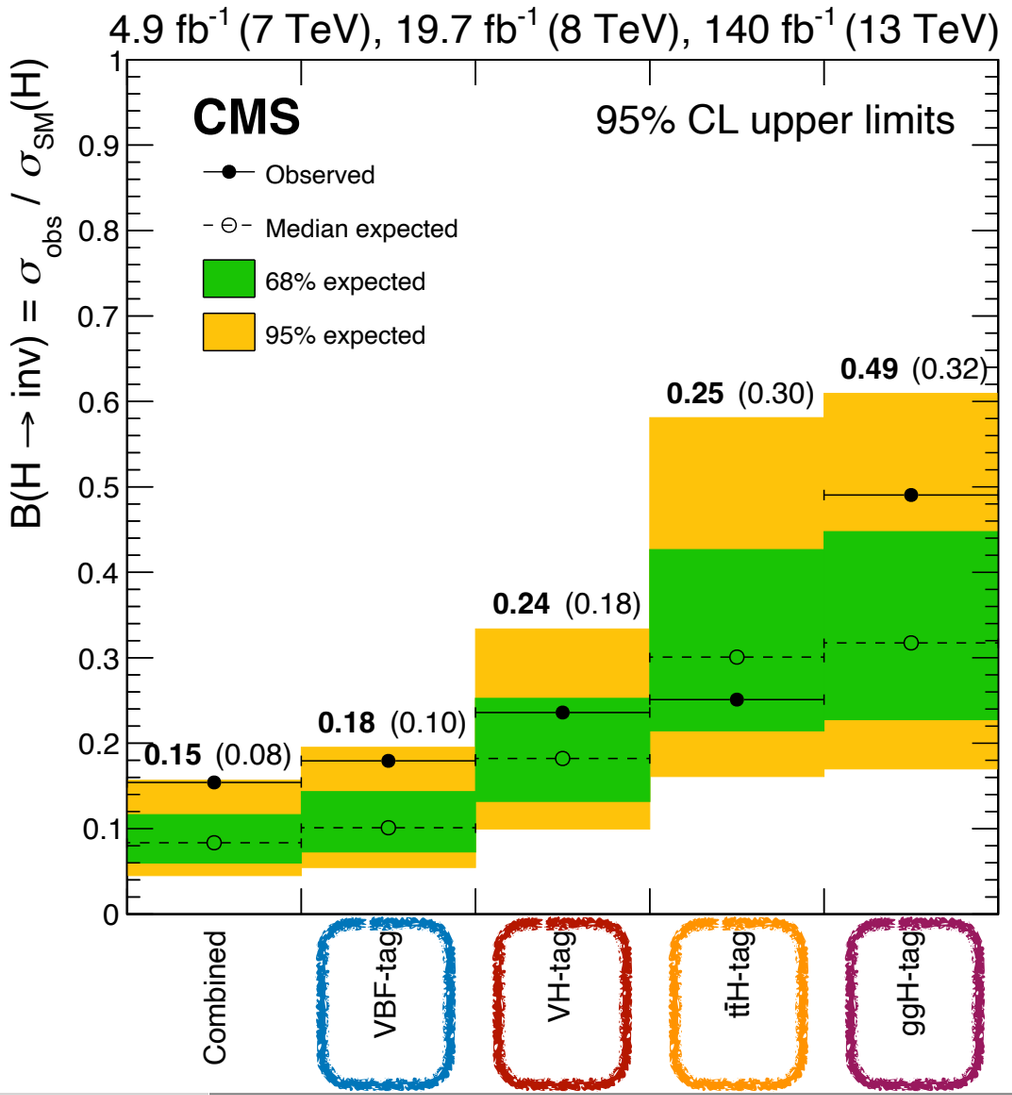

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Category	Observed	Median expected
2012–2016	0.33	0.21
VTR 2017	0.57	0.45
VTR 2018	0.44	0.34
VTR 2017+2018	0.40	0.28
MTR 2017	0.25	0.19
MTR 2018	0.24	0.15
MTR 2017+2018	0.17	0.13
all 2017	0.24	0.18
all 2018	0.25	0.15
all 2017+2018	0.18	0.12
2012–2018	0.18	0.10

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Final result:

- Upper limit on $\mathcal{B}(H \to inv) < 0.15\ (0.08)$
- Scan for κ_V and κ_F

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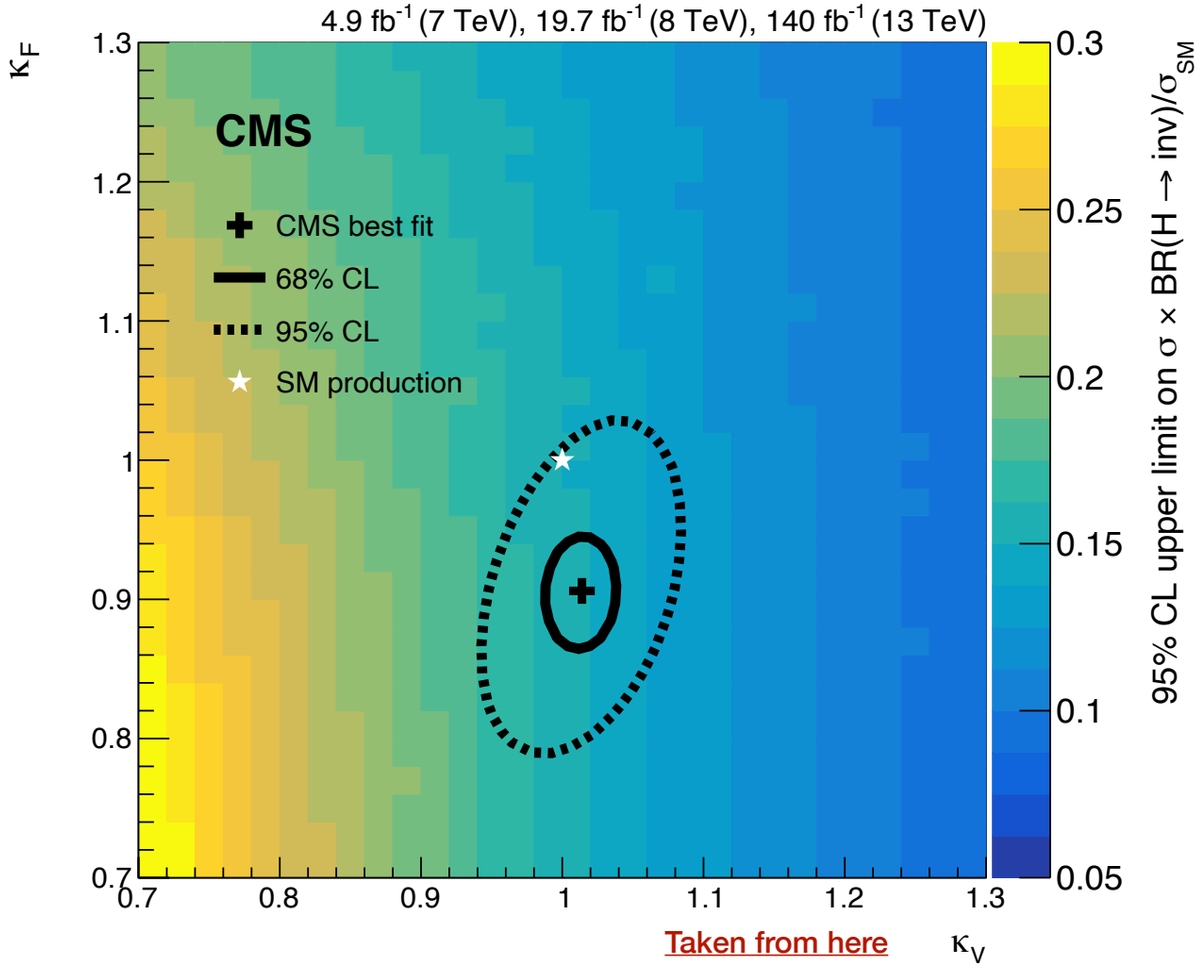

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Dark matter interpretations

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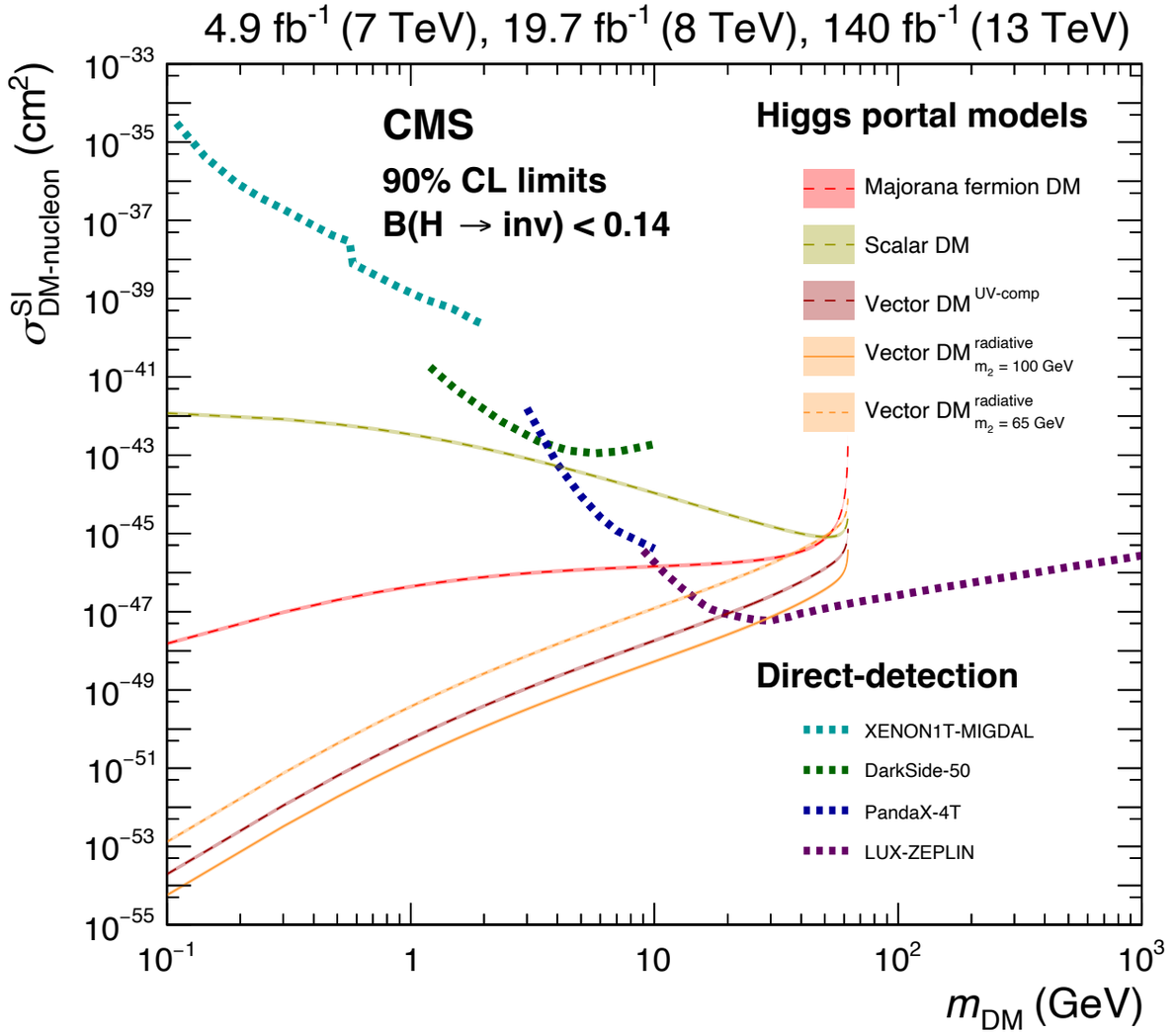
Higgs-portal models

- Stable dark matter candidates couple to Higgs
  - Assume $m_{DM} < \frac{m_H}{2}$
  - EFT approach for DM-nucleon interaction
  - Upper limits on elastic scattering σ
- Orthogonal phase-space wrt direct detection experiments
  - Strongest constraints for masses $< 10\ GeV$



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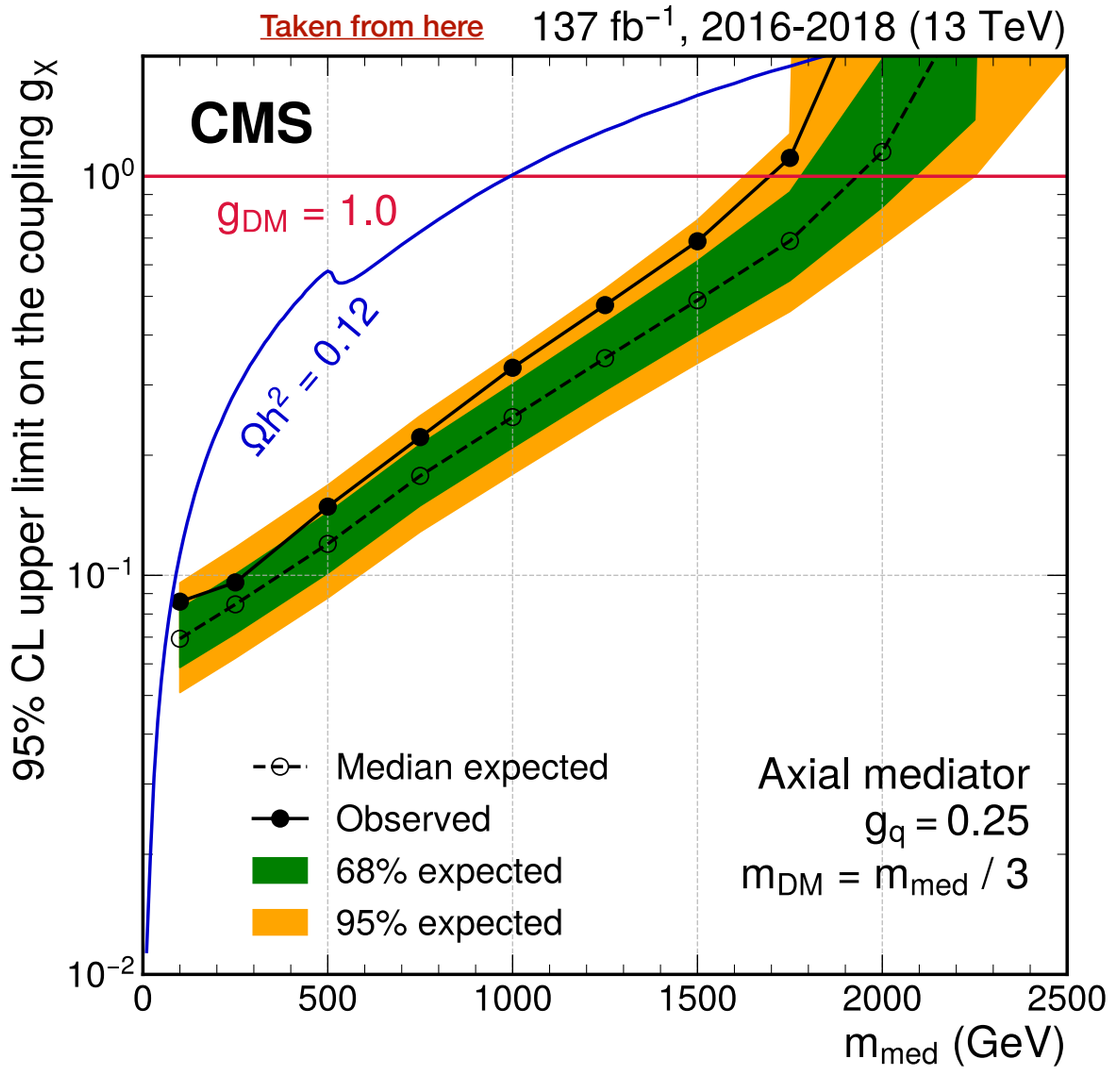
Spin-1 mediator

- Exclusion limits on the couplings and masses
- Considered only for mono+X searches



Summary and Outlook

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  - Complementary phase-space, production modes and final states investigated
- Constraints on SM Higgs boson properties:
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- Stay tune for more results:
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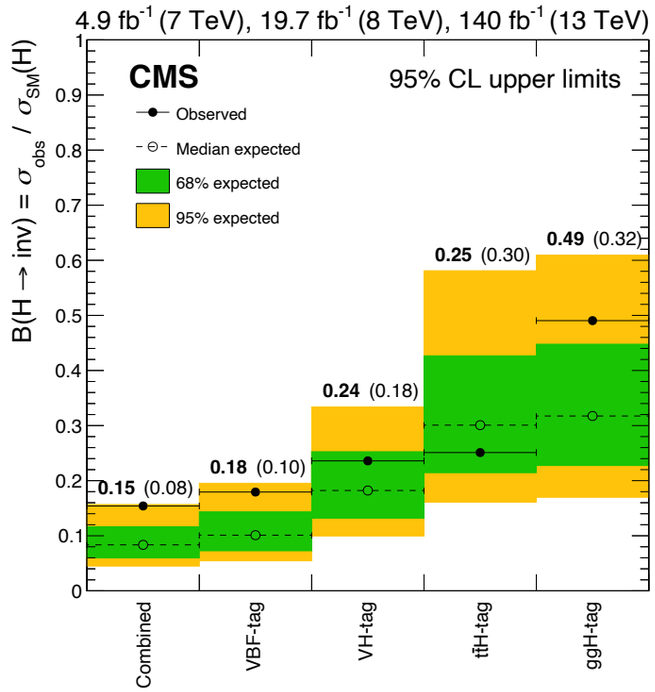
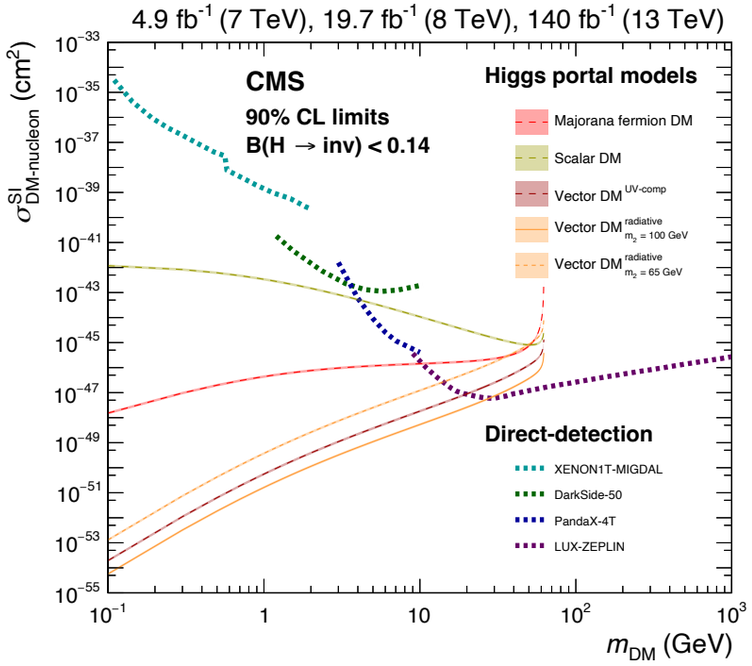
  - ... new techniques
  - ... reduction of systematics





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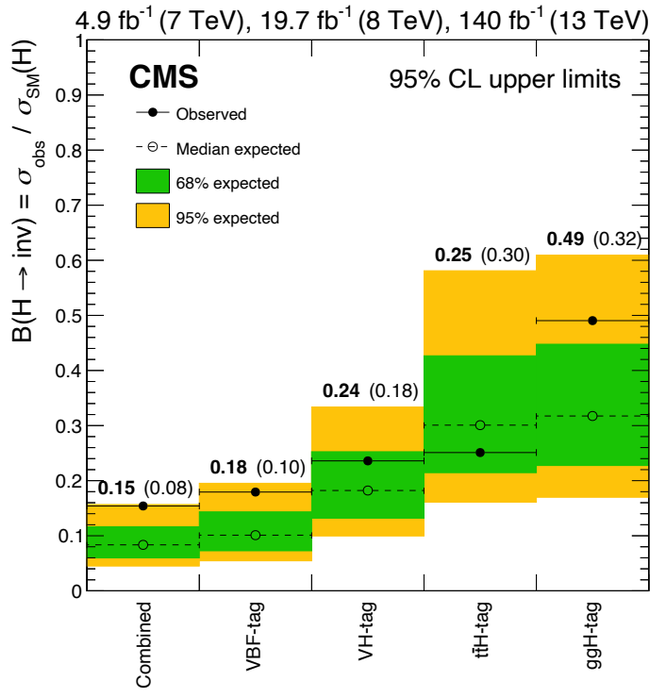

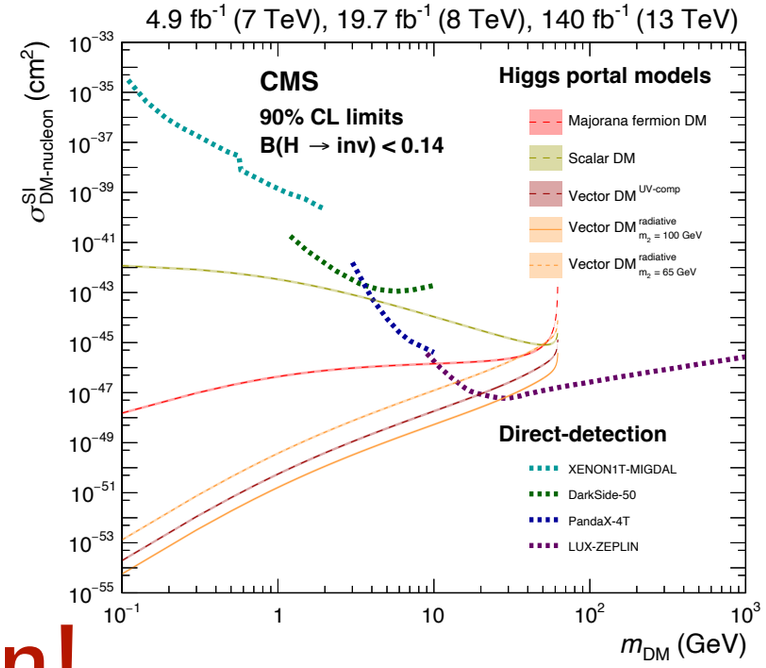

Thank you for your attention!