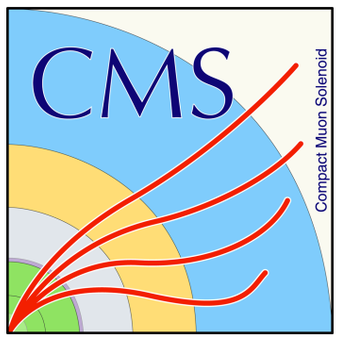
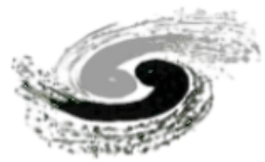
Searches for Higgs Invisible

Vukasin Milosevic (IHEP Beijing)
on behalf of the CMS Collaboration



EPS-HEP CONFERENCE 2021
26-30.7.2021.

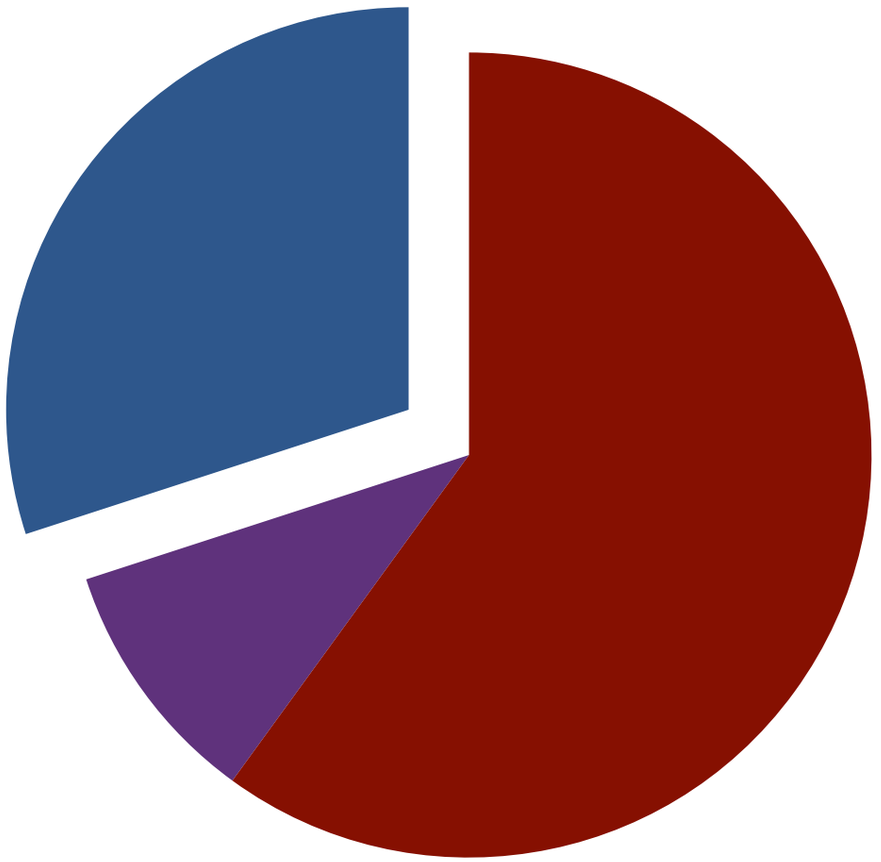


中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

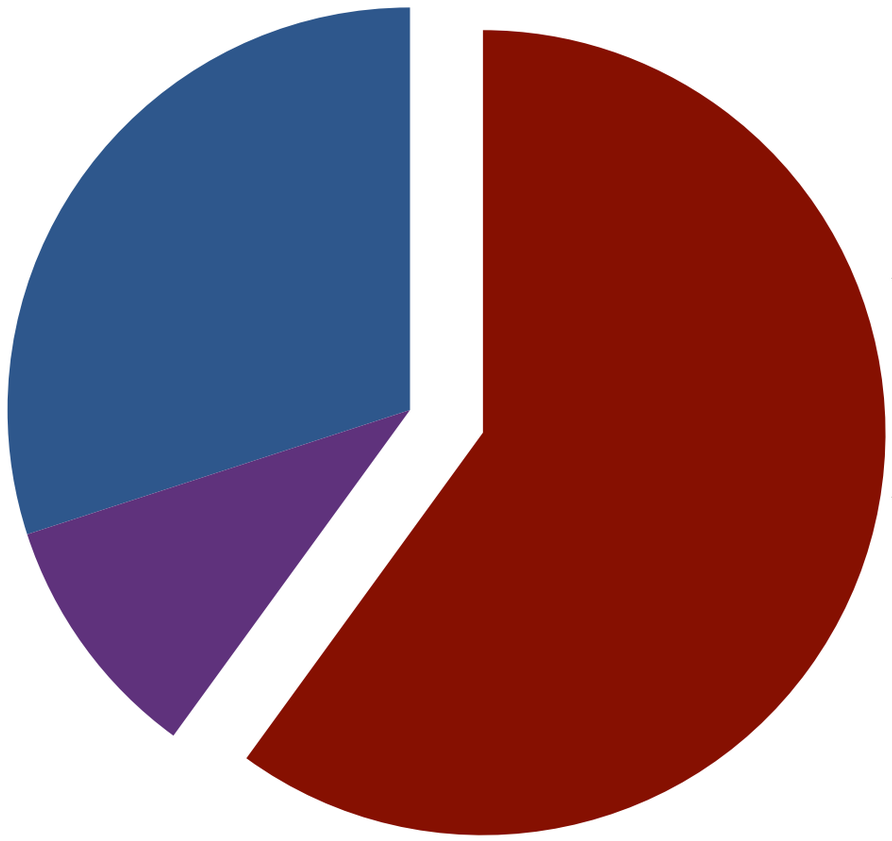
Introduction

Motivation

- Why are we interested in the invisibly decaying Higgs?
- What are the main topologies of interest and strategies?



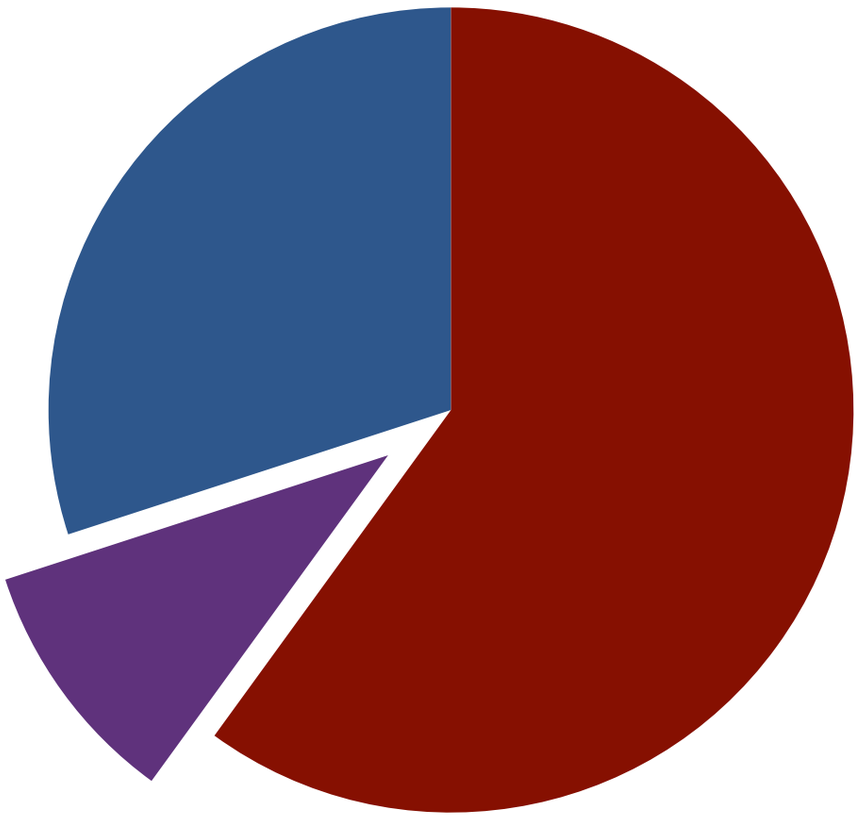
Introduction



H(invisible) status

- What are the previous results?
  - Early Run 2 combination
- What is new in terms of full Run 2 measurements?

Introduction



Future projections and summary

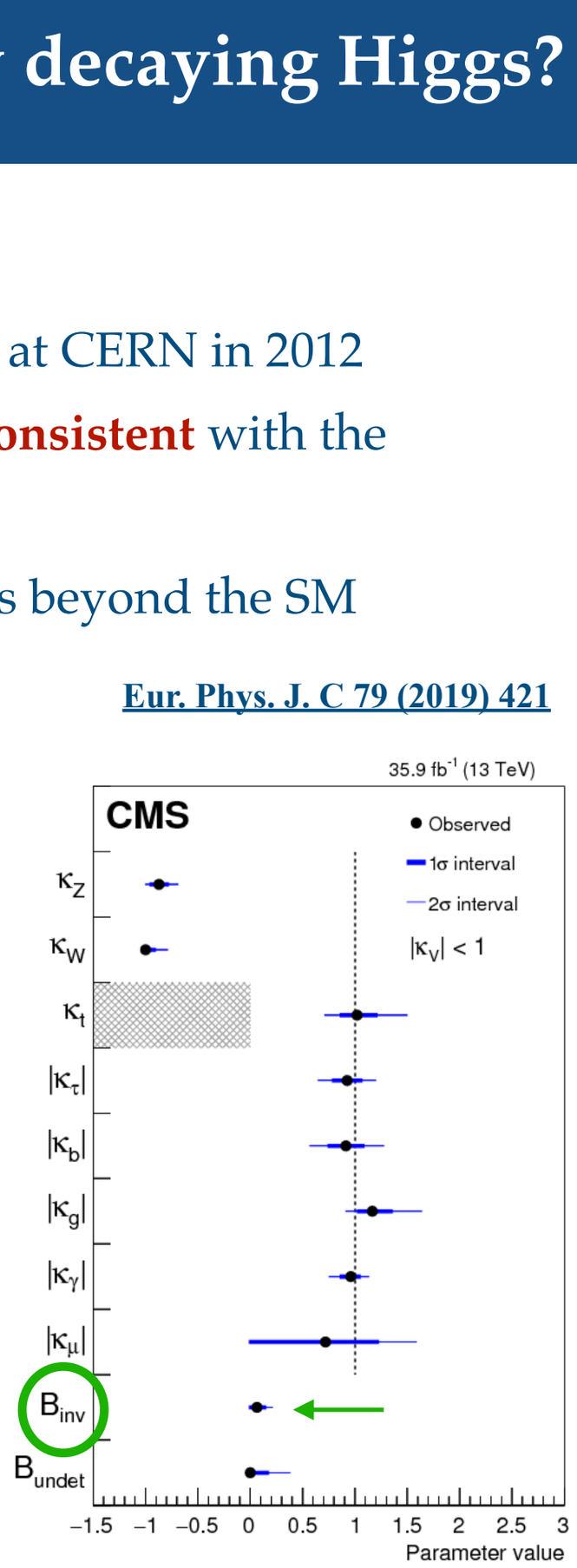
Motivation: Why the interest for the invisibly decaying Higgs?

- **The "crown jewel" of the experimental particle physics:**
  - Higgs boson was discovered by **ATLAS** and **CMS experiments** at CERN in 2012
  - All of the following measurements of its properties have been **consistent** with the **Standard Model (SM)**
  - Large uncertainties of these measurements can allow for physics beyond the SM

Why the interest in the invisible final state?

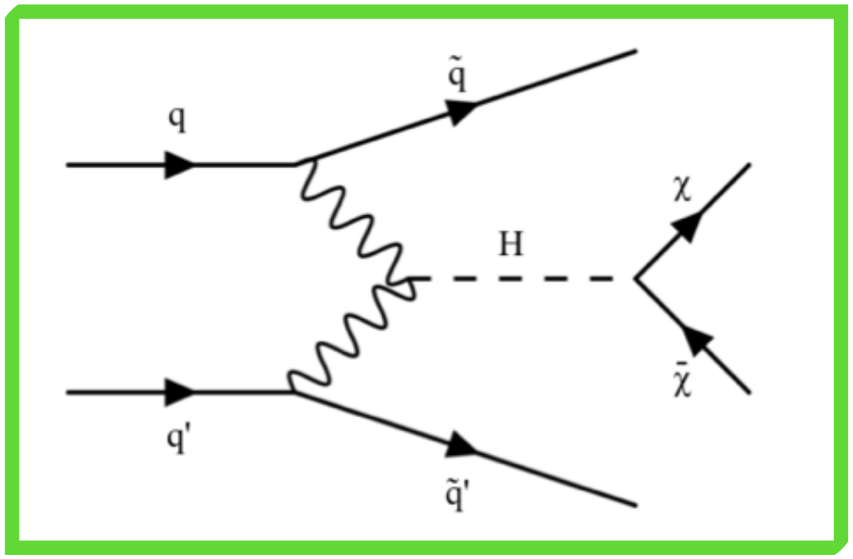
- **According to the SM, the probability of Br(H → 4ν) ~ 0.1 %**
  - **Can represent a good way of testing for BSM physics!**
  - **Higgs boson** could be a **mediator between SM and DM** sector
  - Detection would require it to recoil against a visible system

Eur. Phys. J. C 79 (2019) 421

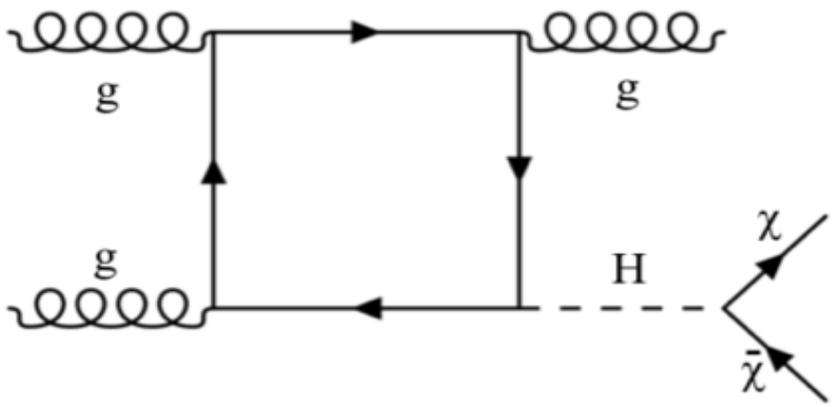


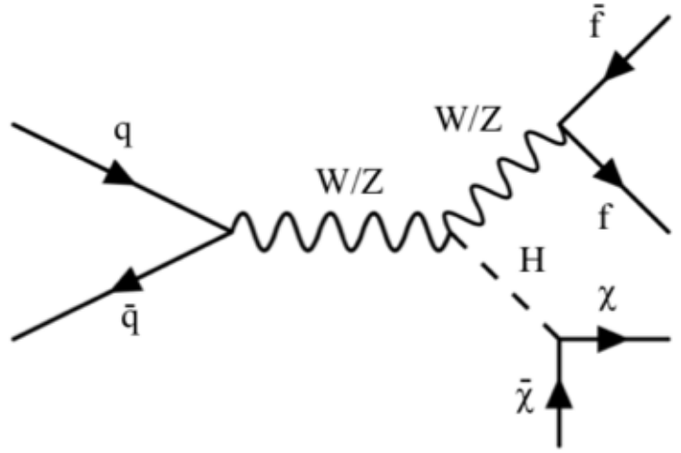
Motivation: Why the interest for the invisibly decaying Higgs?

- **Higgs boson can take a role of a mediator between SM and DM particles:**
  - Detection requires for the **Higgs to recoil against a visible system**
  - **Large** missing transverse energy **(MET)**



- **qqH : Higgs boson is produced in a vector boson fusion topology (VBF)**
- VH: Higgs boson production with a vector boson
- ggH: Higgs boson produced via gluon fusion.





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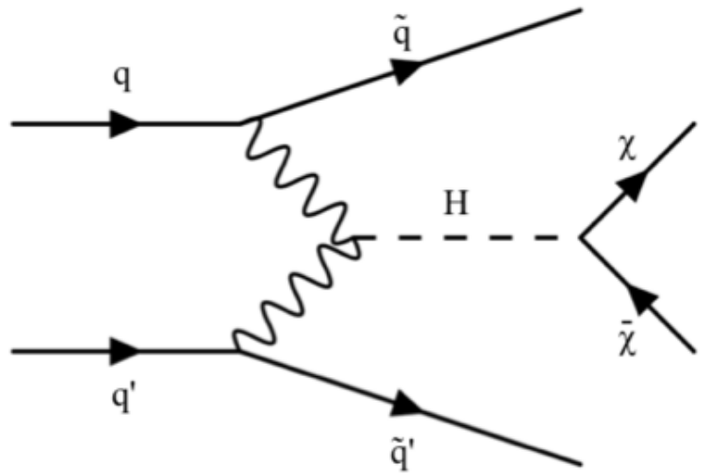

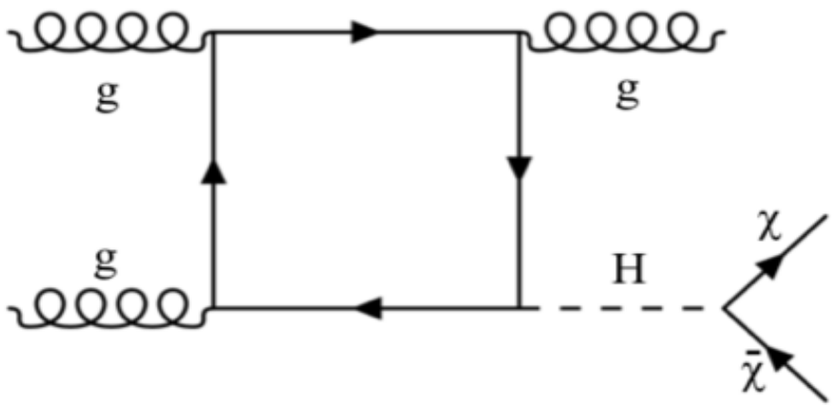

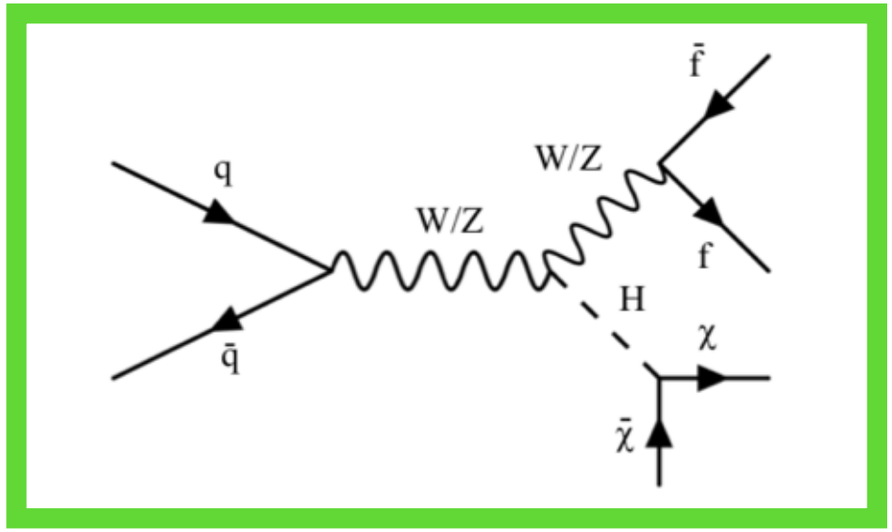

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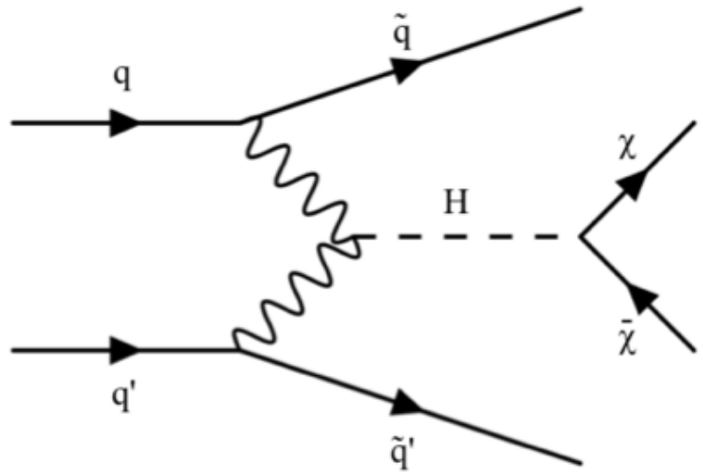
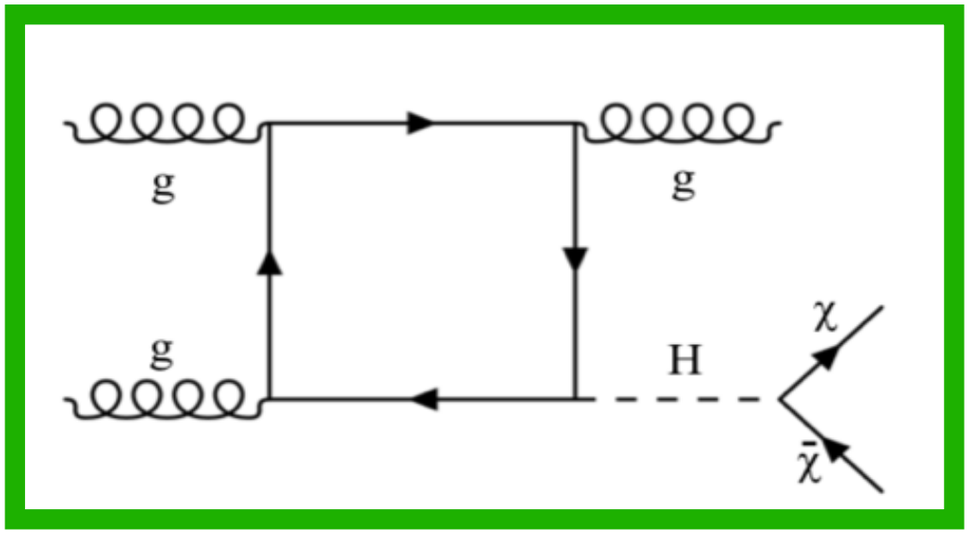
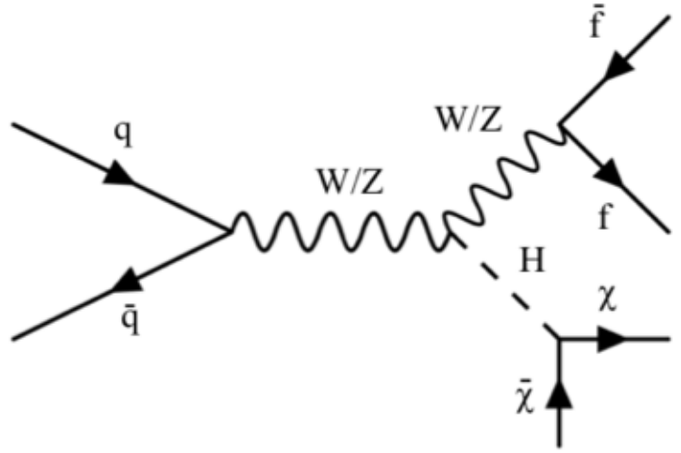


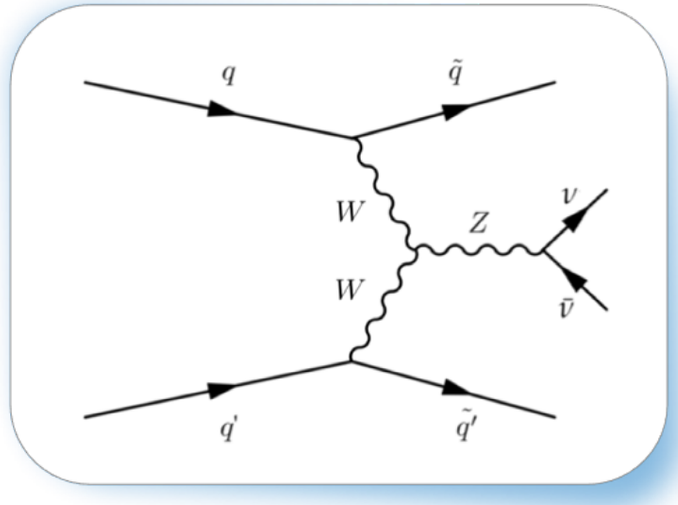




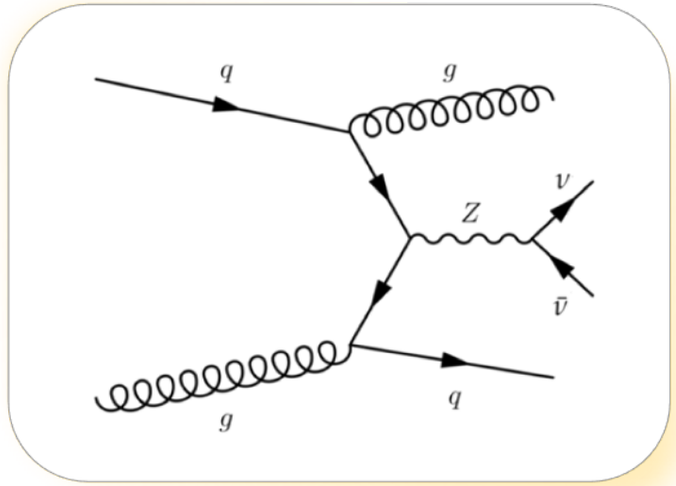
Motivation: VBF production mode

- **VBF production mode of the Higgs boson has a characteristic signature:**
  - **Two jets** with a **large geometrical separation**
  - **High dijet invariant mass** (a good way to control S/B)
  - Represents a channel with the largest sensitivity

- **Main backgrounds:**
  - **QCD and EWK produced V+jets (where V= W/Z)**
    - Irreducible when Z->νν and W->lν
      - With the charged lepton being missed in the detection



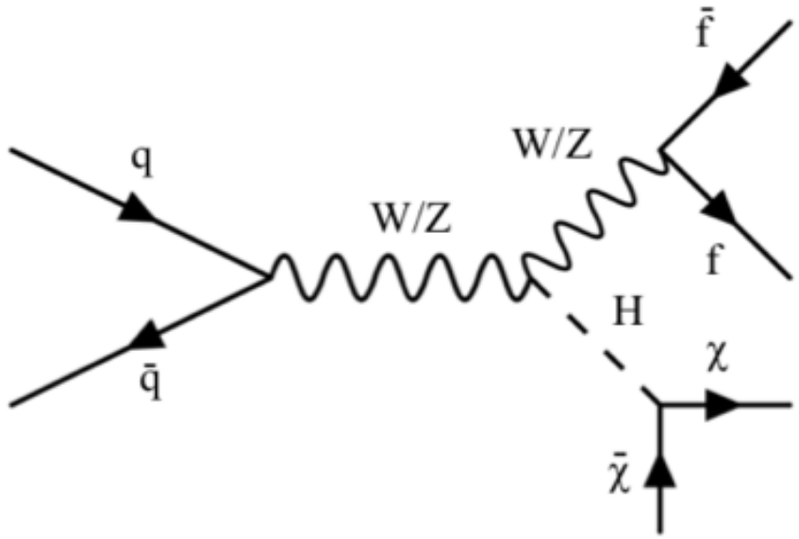
- **Estimated through dedicated control regions in data (CR):**
  - Z or W boson associated with the same dijet topology
  - Resulting in four CRs separated by lepton flavour (e/μ)



- **QCD multi jet processes - data driven estimation**

Motivation: VH production mode

- **Mono V channel:**
  - Main characteristics:
    - Energetic jets - due to V(qq)
    - Imbalance in MET due to undetected particles
- **Mono Jet channel:**
  - Main characteristics:
    - A jet originating from ISR
    - Interpreted as ggH production associated with one jet
- **Z(ll)H channel:**
  - Main characteristics:
    - The production of a lepton pair originating from Z(ll)
    - A large MET



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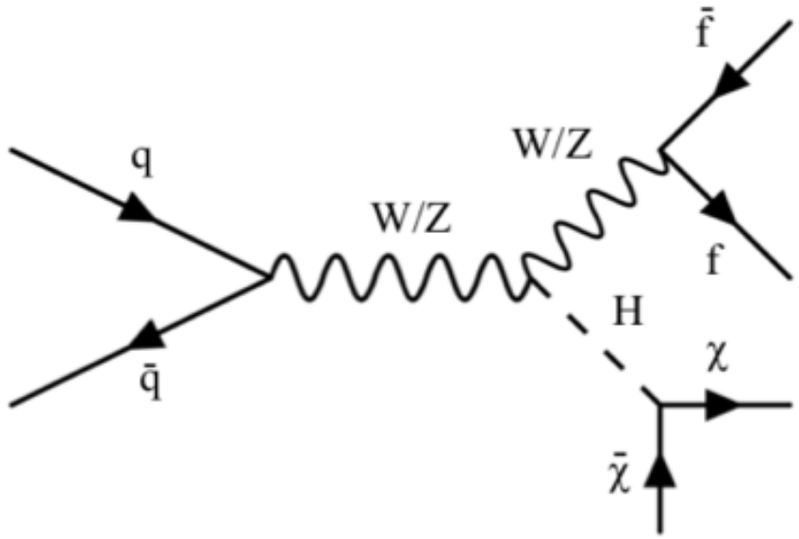

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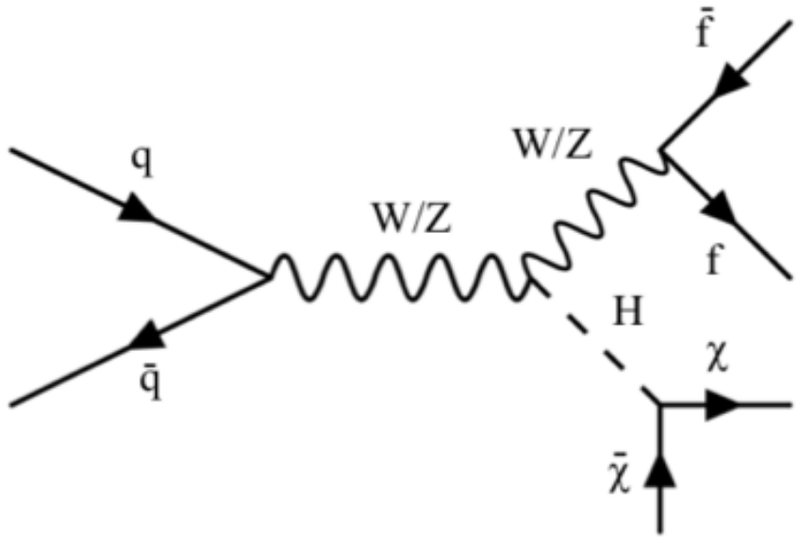
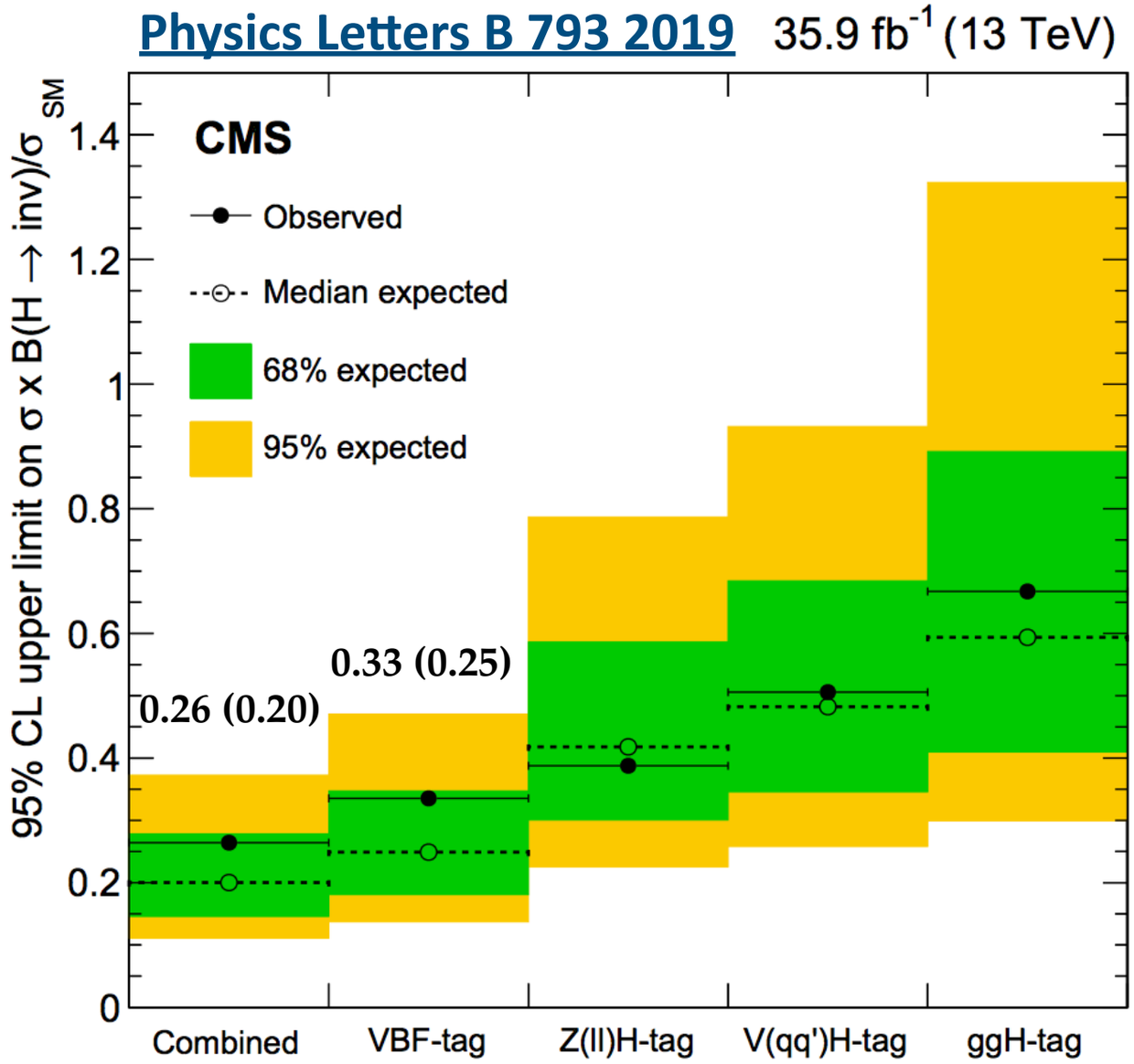


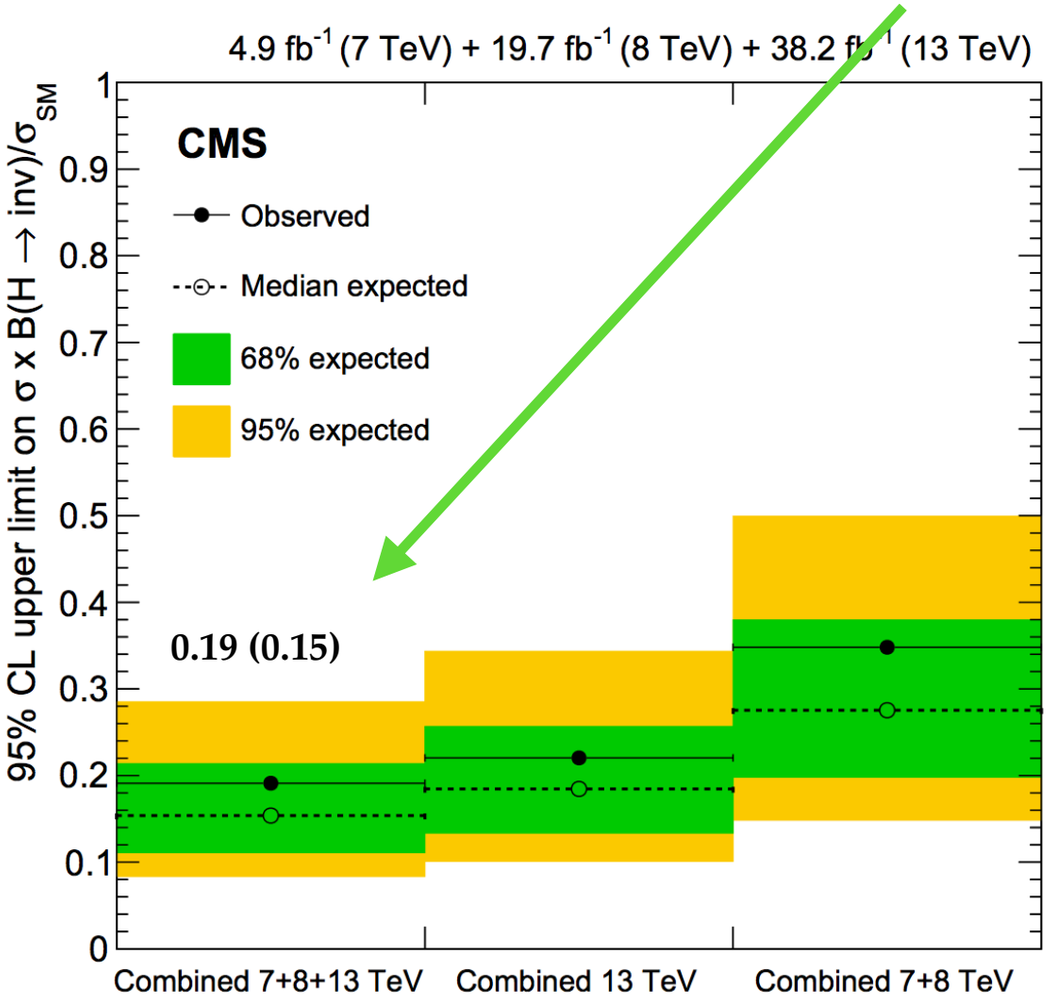
Where are we now? Early Run 2 combination

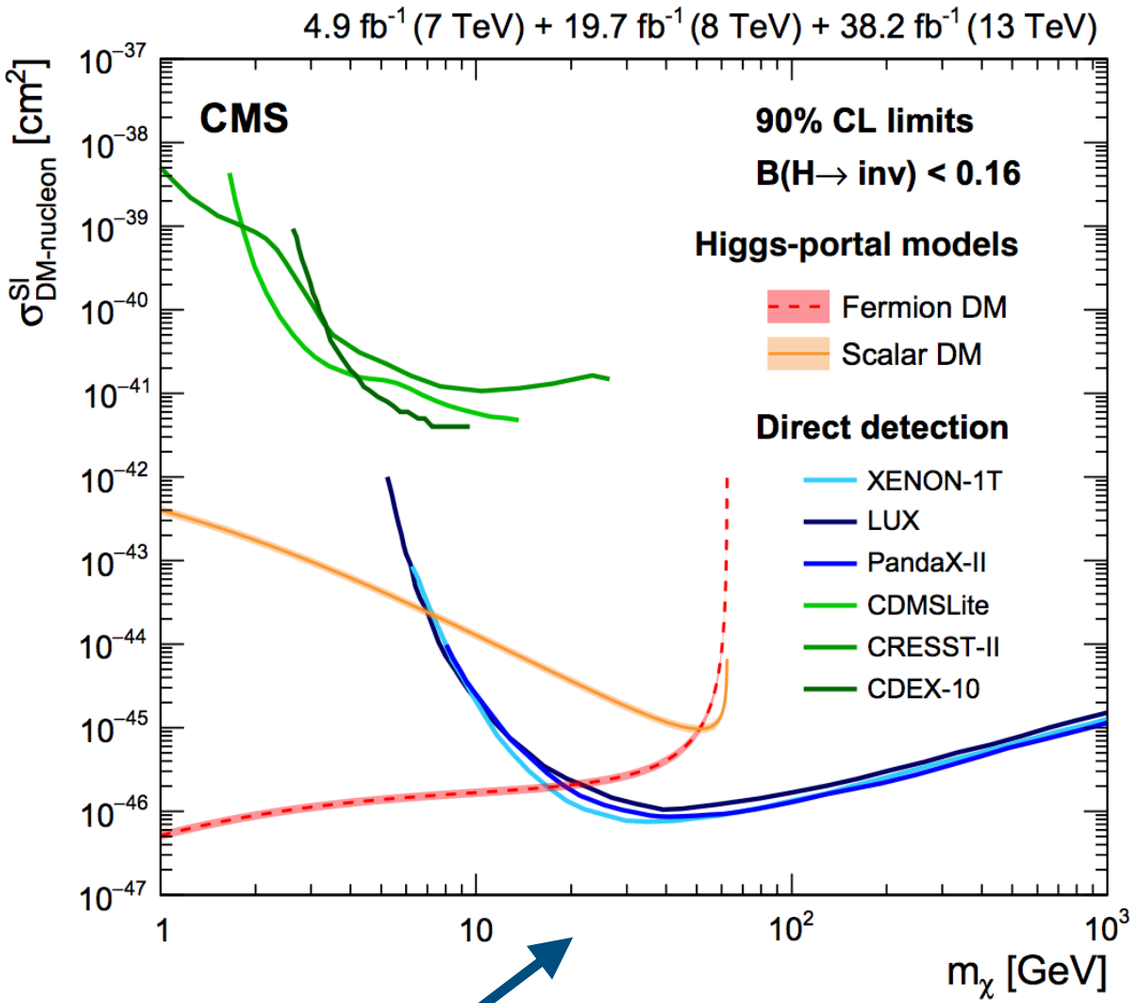
- **The first combination measurement using Run 2 data was published using the 2016 dataset**
- **No significant deviation from the SM was reported:**
  - The result of the measurement is expressed as the **95% CL upper limit on the B(H → inv.)**



Where are we now? Run 1 + early Run 2 combination

- **This publication also included a first combination of Run 1 and 2015+2016 data**
  - Setting the B(H → inv) limit to be at **0.19 (0.15)** for the observed (expected) value



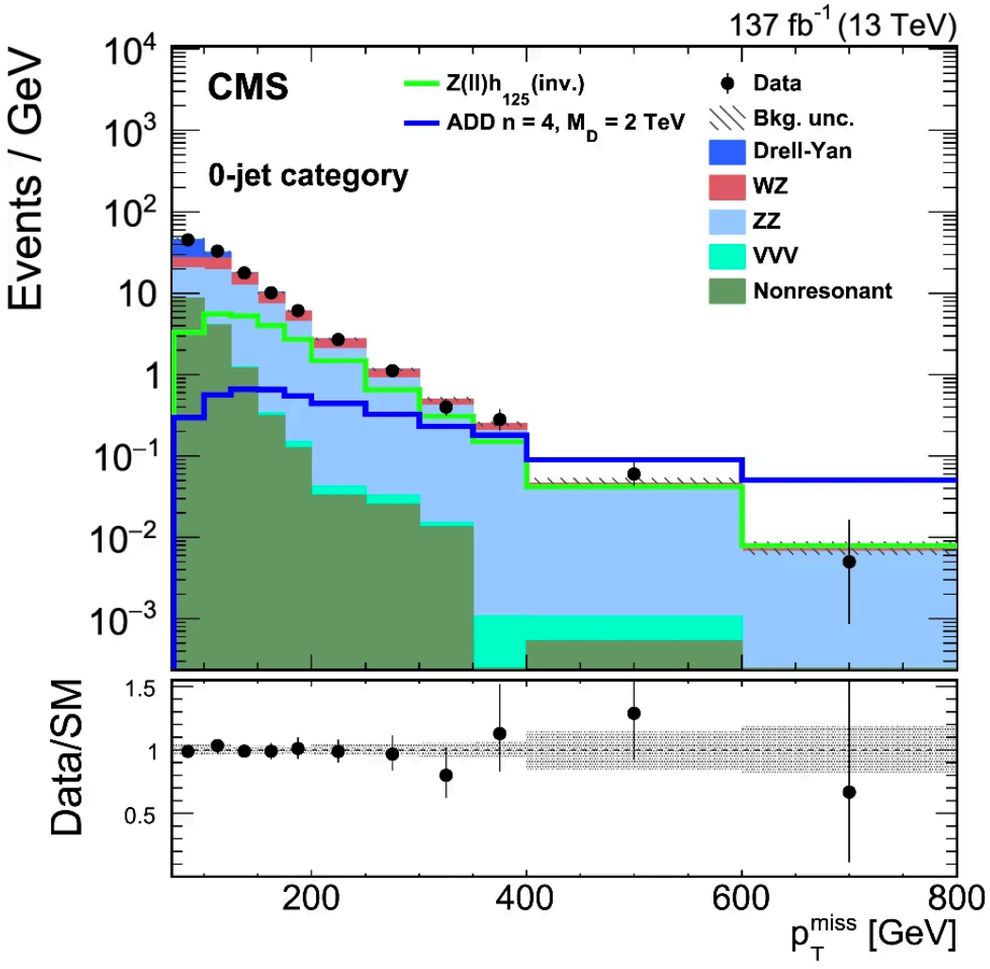


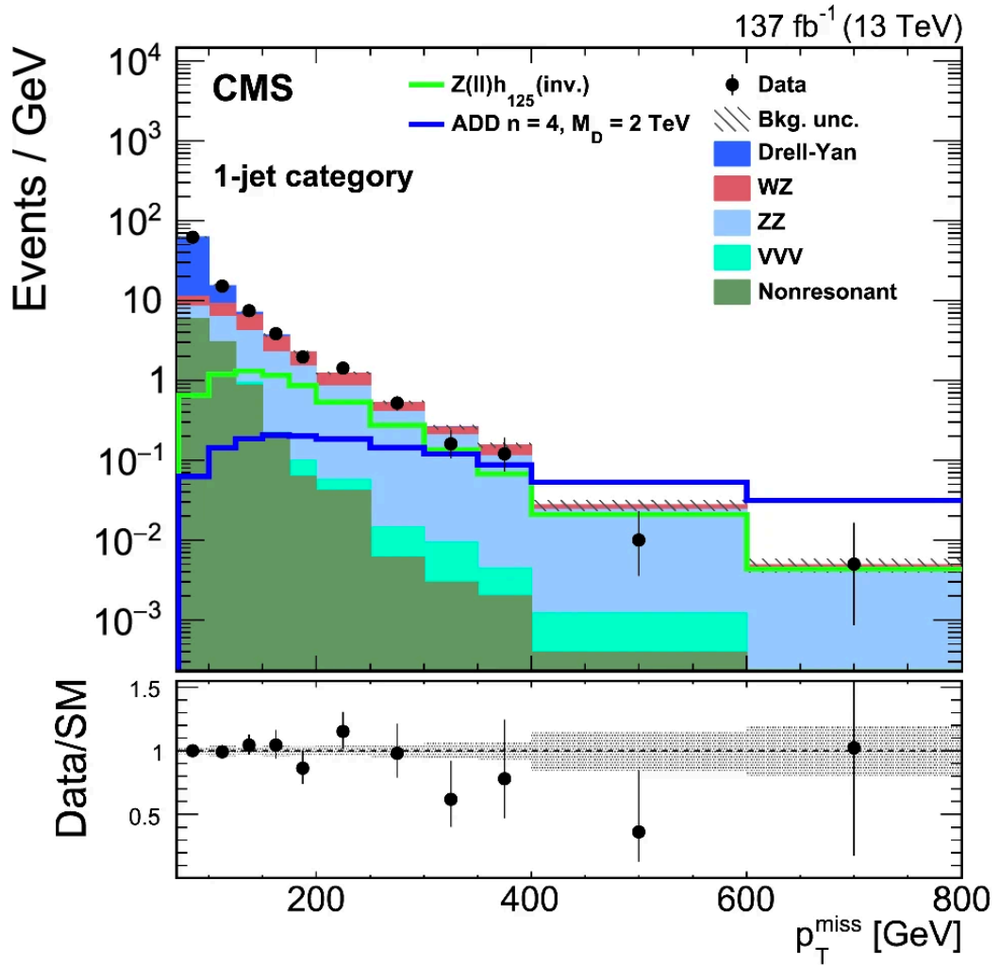
Physics Letters B 793 2019

- 90% CL upper limits on the spin-independent DM-nucleon scattering cross section in Higgs portal models, assuming a scalar or fermion DM candidate.

Z(ll)H(invisible): Full Run 2 measurement

- **The Z(ll)H(invisible) measurement using full Run 2 data**
  - Interpretation of a wider search for **Dark Matter in association with a Z boson (EPJC 81 2021)**
  - No significant deviation from the Standard Model was reported
  - **The observed (expected) 95% CL upper limit computed using m_H= 125 GeV:**
    - **B(H → inv) = 0.29 (0.25)**





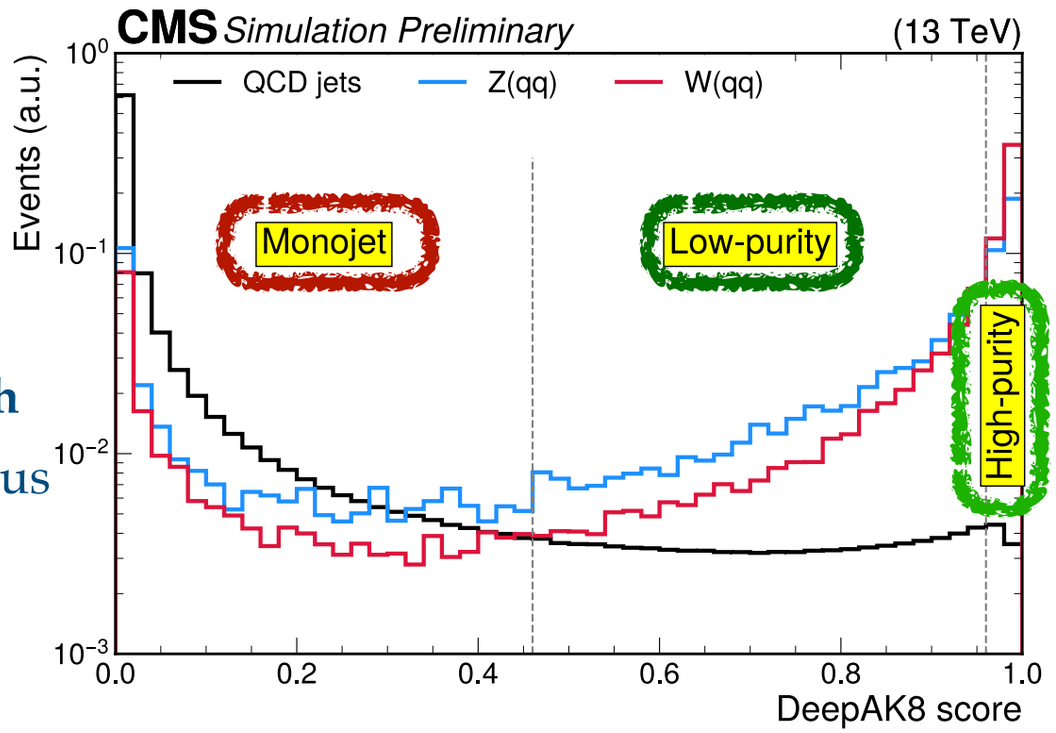
Mono jet/mono V: Full Run 2 measurement - Overview

- **The mono jet/mono V measurement using full Run 2 data**
  - Interpretation of a wider search for **new particles in association with jets and** $E_{T,miss}$
    - **Published in: CMS-PAS-EXO-20-004**

- **Implementation of ML techniques in search for the V(qq) events (separating from QCD multijet events)**
  - Neural network tagger - categories based on the DeepAK8 tagger score (JINST 15 P06005)
  - **High purity VH (90% VH), Low purity VH (40% VH)** and **mono Jet (75% ggH, 20% VBF)**

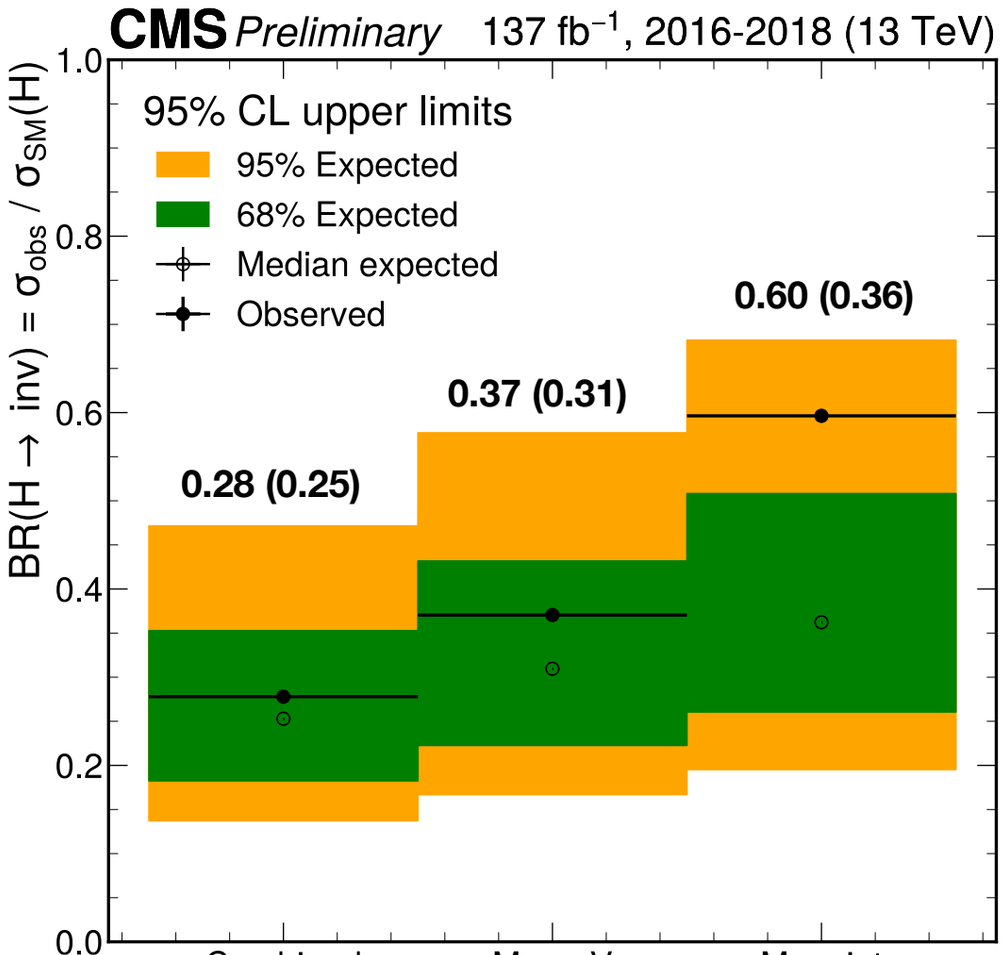
- **Performing a simultaneous fit in the Signal Region (SR) and Control Regions (CRs):**
  - **In bins of the** $E_{T,miss}$

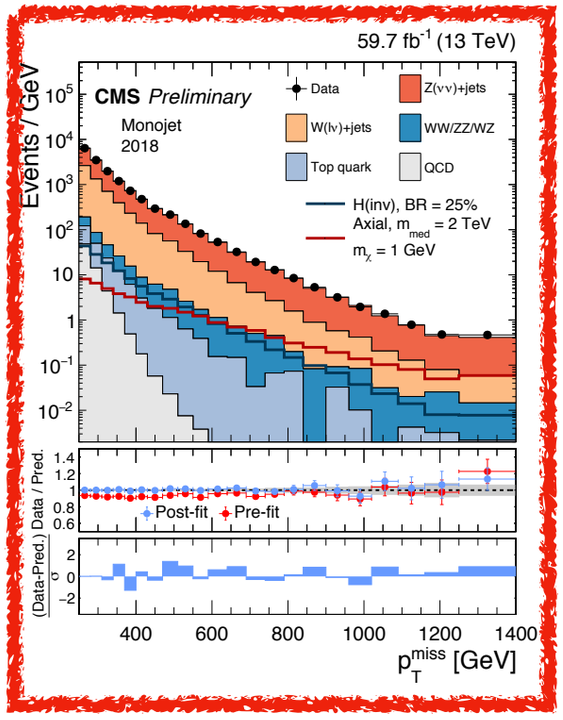
- **Connecting the CRs to the SR using the Transfer Factor approach**
  - **Z(νν)** and **W(lν)** normalization estimated from a simultaneous CR+SR fit
  - Dedicated CR region for QCD multijet estimation

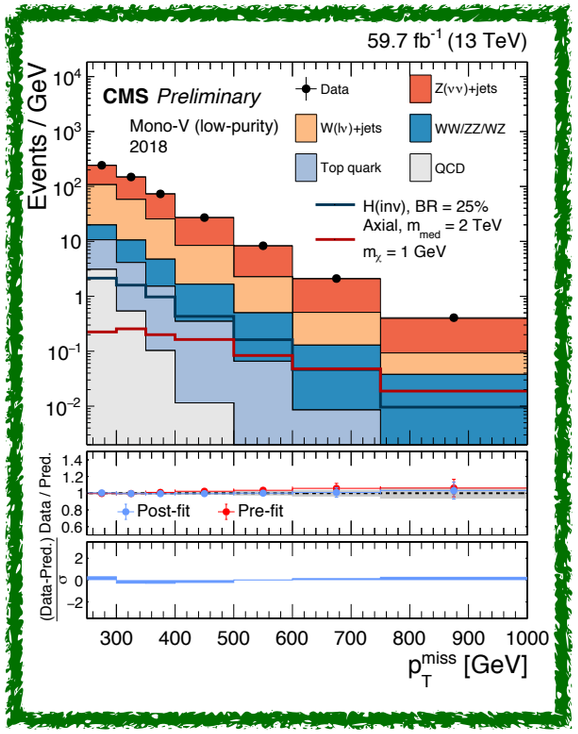


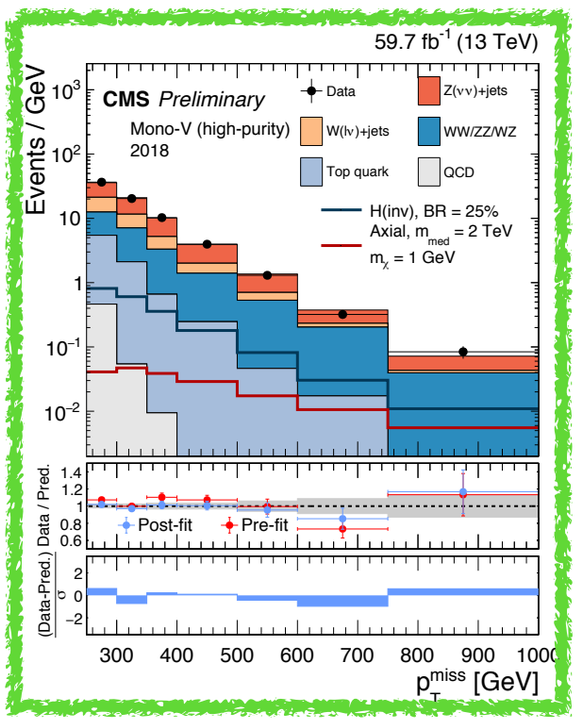
Mono jet/mono V: Full Run 2 measurement - Results

- **The mono jet/mono V measurement using full Run 2 data**
  - No significant deviation from the Standard Model was reported
  - **The observed (expected) 95% CL upper limit computed using m_H= 125 GeV:**
    - **B(H → inv) = 0.28 (0.25)**



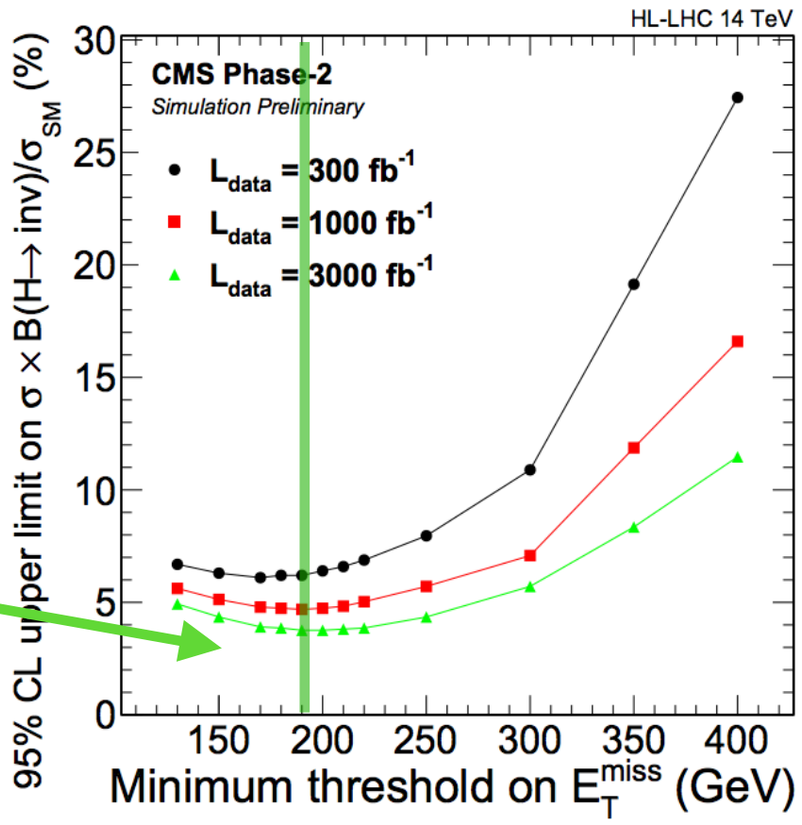


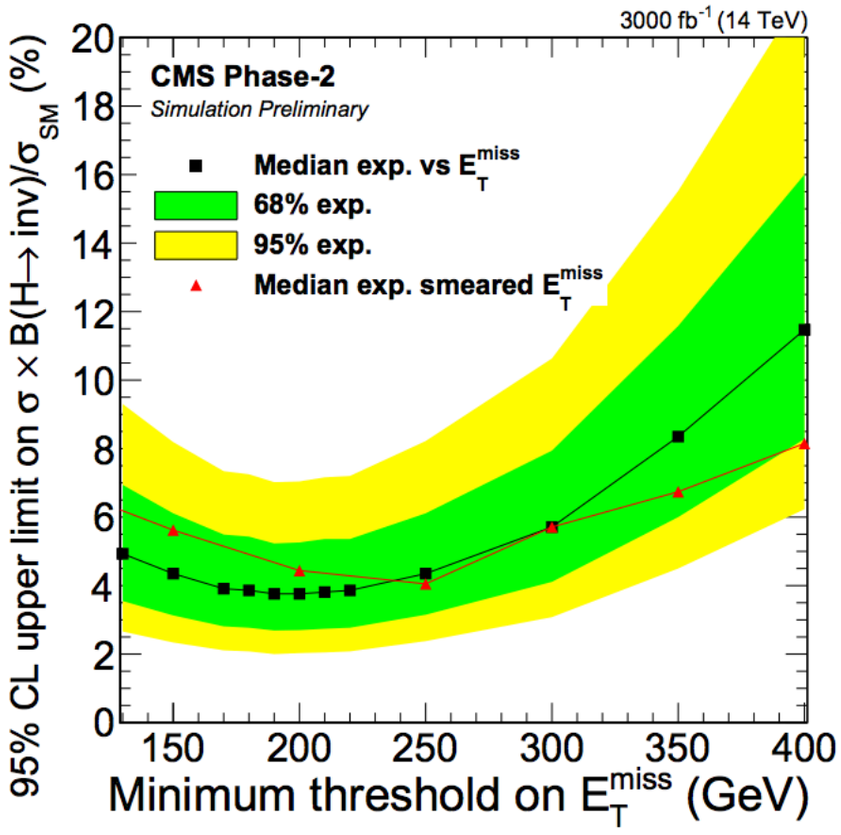




Future prospects

- **VBF H(invisible) was chosen for the HL-LHC study (CYRM-2019-007.221)**
  - The most sensitive channel
  - Three different simulated scenarios for $\mathscr{L}_{total}$ = 300, 1000, 3000 fb $^{-1}$
- **Performing a set of fits in dijet mass for different versions of $E_{T,miss}$ selection**
- **For the best case scenario: B(H → invisible) = 3.8%**
  - But, this requires production mode targeting triggers
    - Need for a much lower $E_{T,miss}$ selection than previously used





- **A similar study performed by the ATLAS Collaboration**
  - Targeting the the second most sensitive channel - the VH production mode
  - Projects a limit of B(H → invisible) = 8%
- **Under the assumption that both experiments perform similarly in all channels**
  - Combination yields a projected limit of 2.5% for the HL-LHC phase

Summary

- **These slides have summarised the recent H(invisible) studies from the CMS Collaboration:**
  - The **latest combination** focused on the **Run 1 + early Run 2 measurements**
  - Sets a limit on B(H → inv) at 0.19 (0.15) for the observed (expected) value

  - **Measurements using the full Run 2 dataset:**
    - **Z(ll)H(invisible):** B(H → inv) = 0.29 (0.25)
    - **Mono V/mono Jet:** B(H → inv) = 0.28 (0.25)

    - **Results from the measurement of the VBF channel using full Run 2 dataset are being prepared**
      - **Stay tuned!**

- **Studies of future prospects are indicating the need for better triggering approach:**
  - Interesting time for these analyses: CMS future projections at B(VBF H → invisible) = 3.8%
    - But this requires a new trigger strategy to lower the high $E_{T,miss}$ thresholds
    - Possibilities for new approaches (ML vs cut based at the first triggering level)

Thank you for your time!

BACKUP