Institute for Basic Science

PASCOS 2021

Dark matter searches in CMS

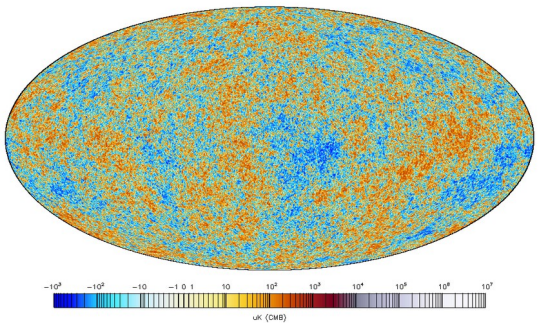
June 16th, 2021

Andreas Albert,
on behalf of the CMS collaboration

BOSTON UNIVERSITY

DM, the LHC and CMS

Dark matter is well-established in the cosmos

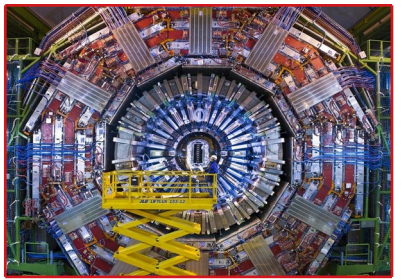


Is it a WIMP?
(weakly interacting massive particle)

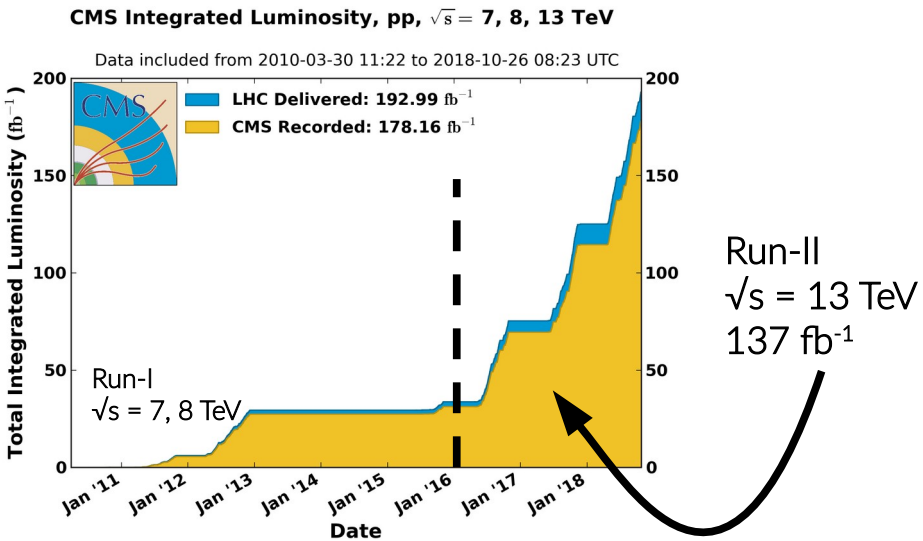
LHC

27 km ring,
√s = 13 TeV

CMS



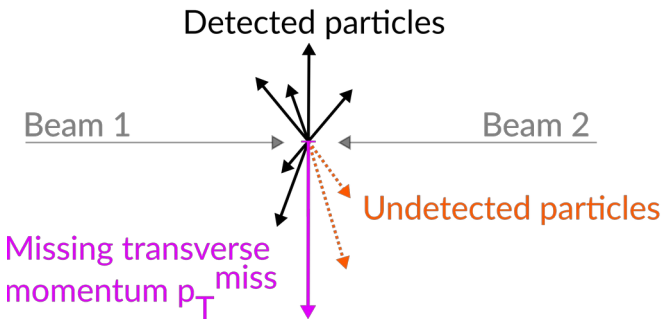
multi-purpose detector
hermetic coverage for |η| <≈ 5



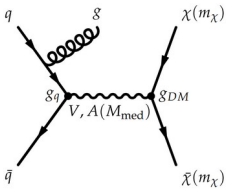
Dark matter detection principle

Dark matter particles would not be detected directly at the LHC
(DM particle flux) × (interaction probability) just too low

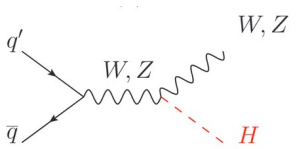
Instead: p_T^{miss} = imbalance of detected particles



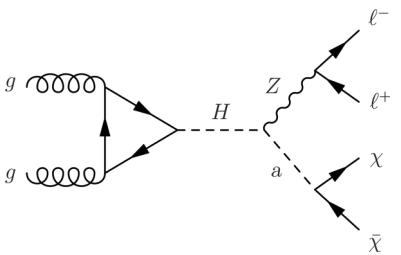
Additional tag particles needed for detection



Basic simplified model
parametrize qq ↔ DM DM
Tag from unavoidable radiation



Higgs portal
Otherwise SM-like Higgs decays to DM
Tag from SM H production



Simplified model with boson interactions
Otherwise SM-like Higgs decays to DM
Tag from SM H production

Monojet + mono-V(qq) search

Combined jet + p_T^{miss} search

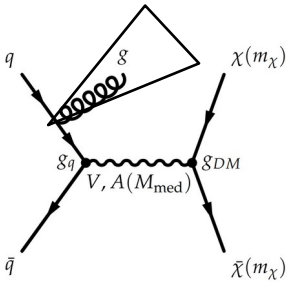
CMS-PAS-EXO-20-004

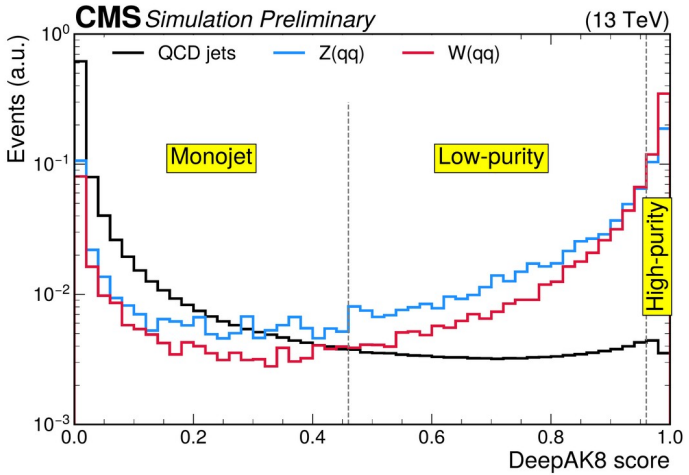
Use neural network tagger to distinguish V(qq) from QCD jets

Generic "DeepAK8" tagger 10.1088/1748-0221/15/06/P06005

Narrow jets from ISR

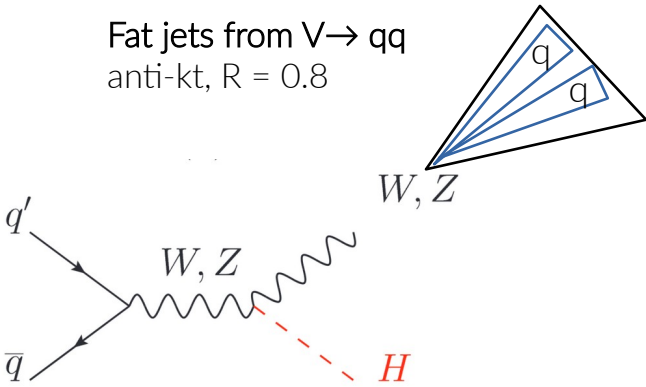
anti-kt, R = 0.4





Fat jets from V→ qq

anti-kt, R = 0.8



Inclusive common selection

p_T^{miss} trigger

p_T^{miss} > 250 GeV

no leptons, photons

one of three categories

Mono-V: Target V(qq)H

fat jet pt > 250 GeV, |η|<2.4

jet mass window 65-120 GeV

- high-purity
- low-purity

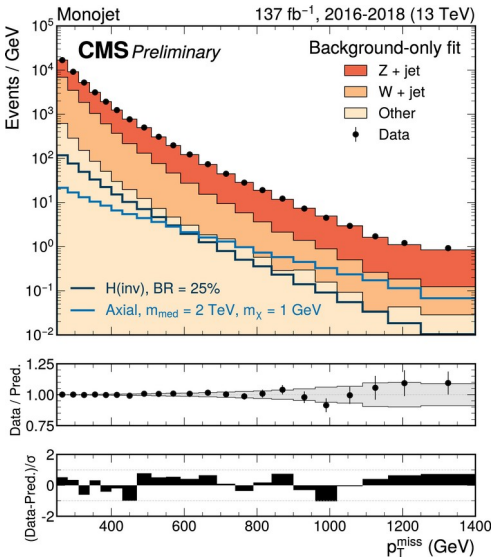
Monojet: QCD ISR jets

narrow jet pt > 100, |η| < 2.4

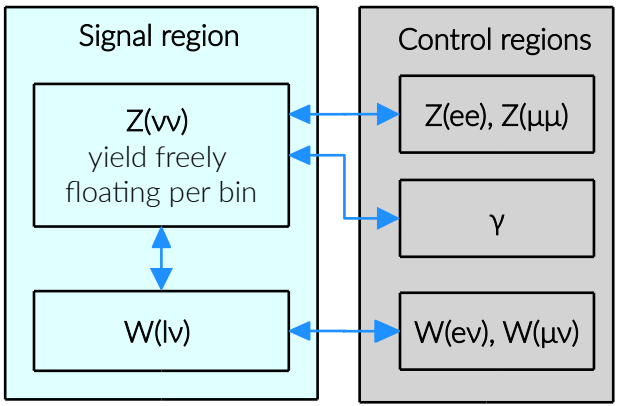
Background estimation

Challenge: Estimate boson p_T in Z(νν), W(lν) over large range

Monojet signal region



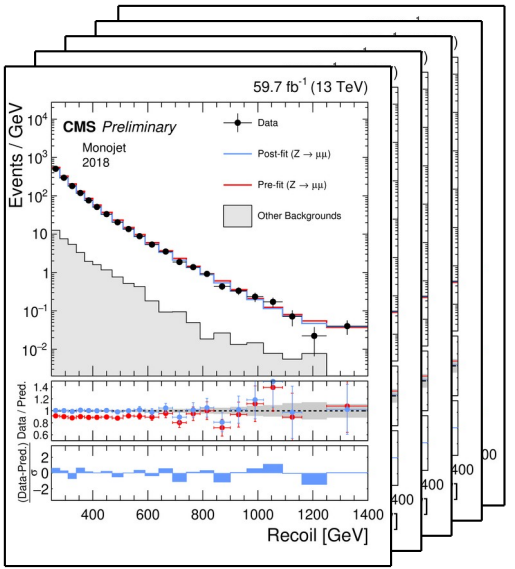
Maximum-likelihood fit



Transfer factors from MC

Normalization and shape from data
→ Common uncertainties cancel
especially theory, jet/p_T^{miss} calibration

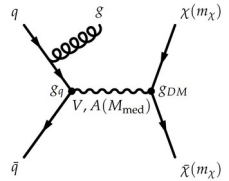
5 control regions per signal region

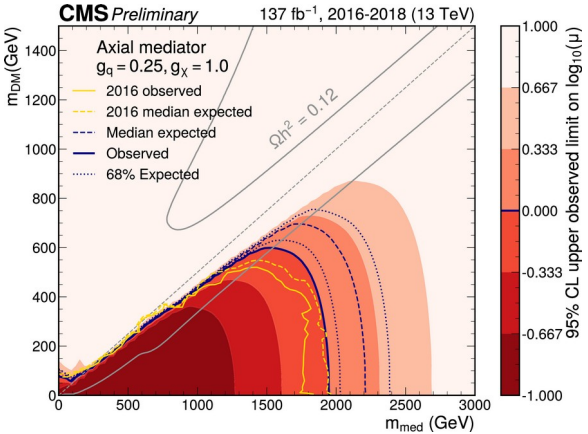


Bounds in plane of mediator (x) and DM mass (y)

Colorless spin-1 mediator

"Drell-Yan inspired"

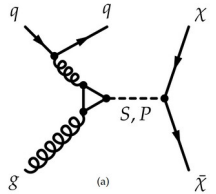


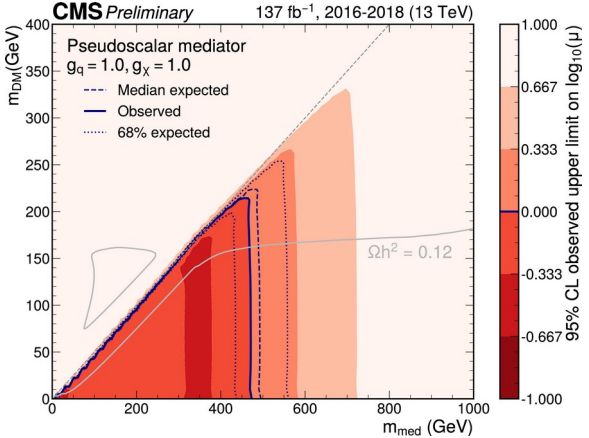


Probe $m_{med} \approx 2$ TeV

Colorless spin-0 mediator

"Higgs inspired" → Yukawa

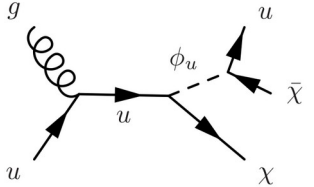


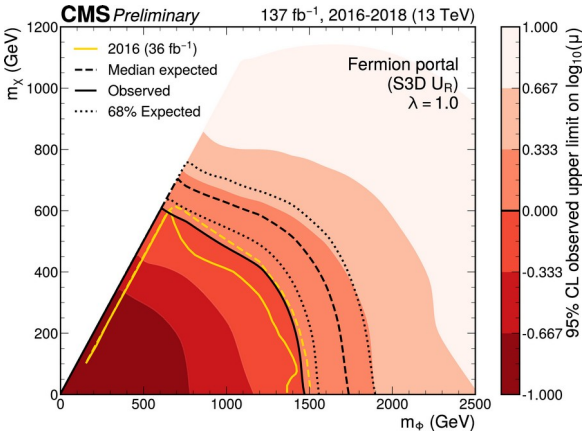


Probe $m_{med} \approx 470$ GeV
(Yukawa suppression)

Colored spin-0 mediator

"Leptoquark inspired"





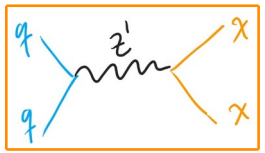
Probe $m_{med} \approx 1.5$ TeV

Dark matter mass sensitivity limited by kinematic boundaries

For recasters: We are publishing simplified likelihood info + MadAnalysis implementation of selection

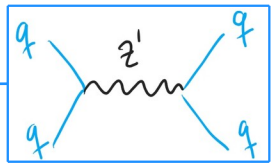
Mediator searches

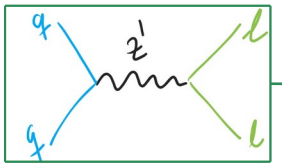
Shooting the messenger



SM SM → DM DM process implies SM SM → SM SM scattering

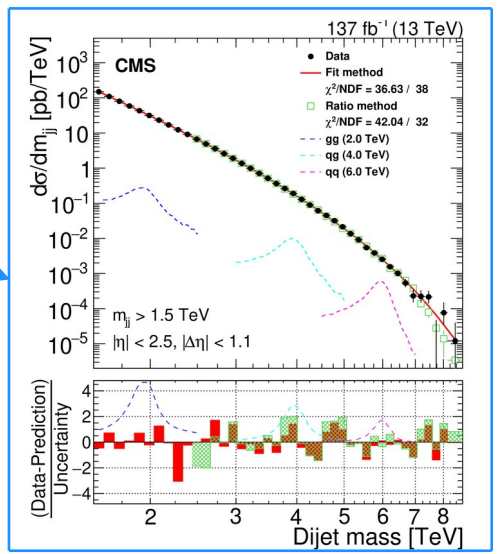
qq ↔ qq unavoidable, qq ↔ leptons possible

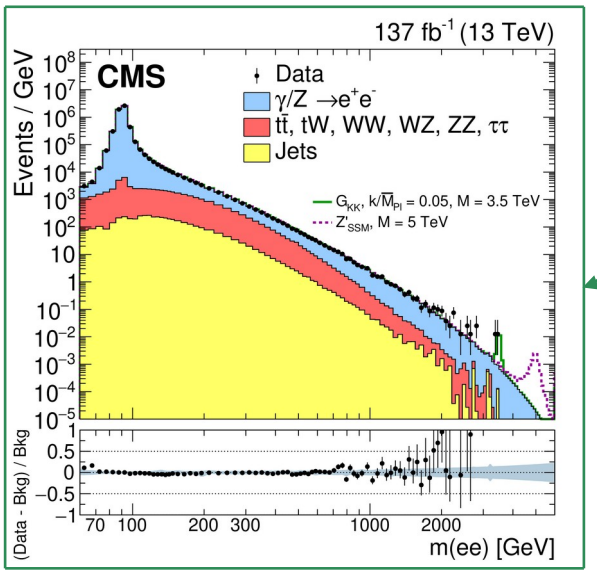




Perform bump hunt to find mediator decays to SM

Dijet
gigantic SM mass range



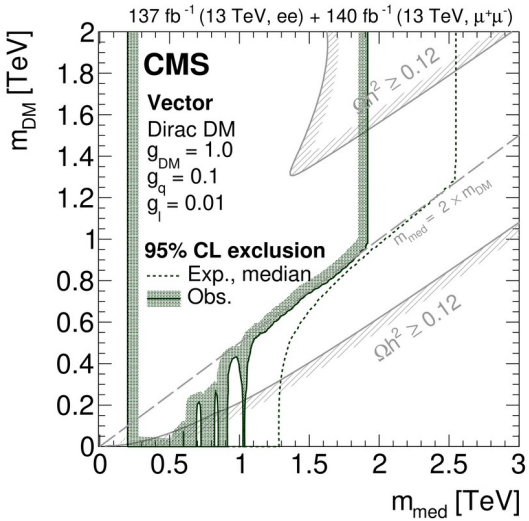


Dilepton
Profit from lepton resolution

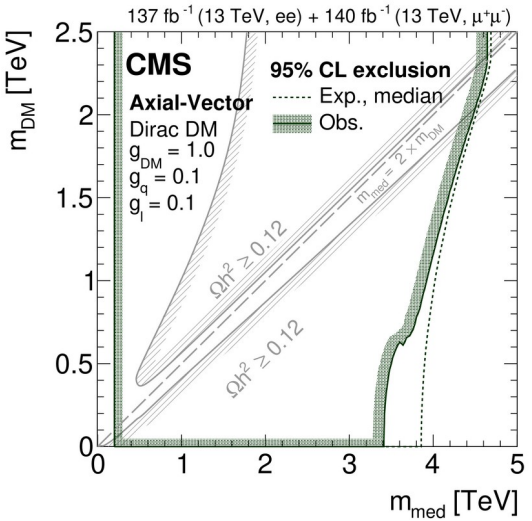
Constraints from mediator searches

Dilepton: Mediator-lepton coupling free

small $g_l = 0.01$

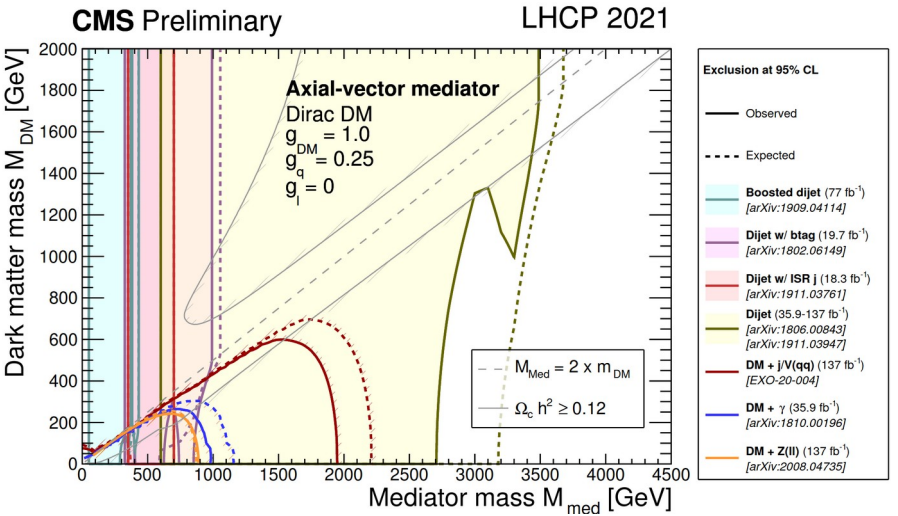


medium $g_l = 0.1$



TeV-range constraints
even for modest lepton couplings

Dijet: Quark coupling benchmark g_q=0.25

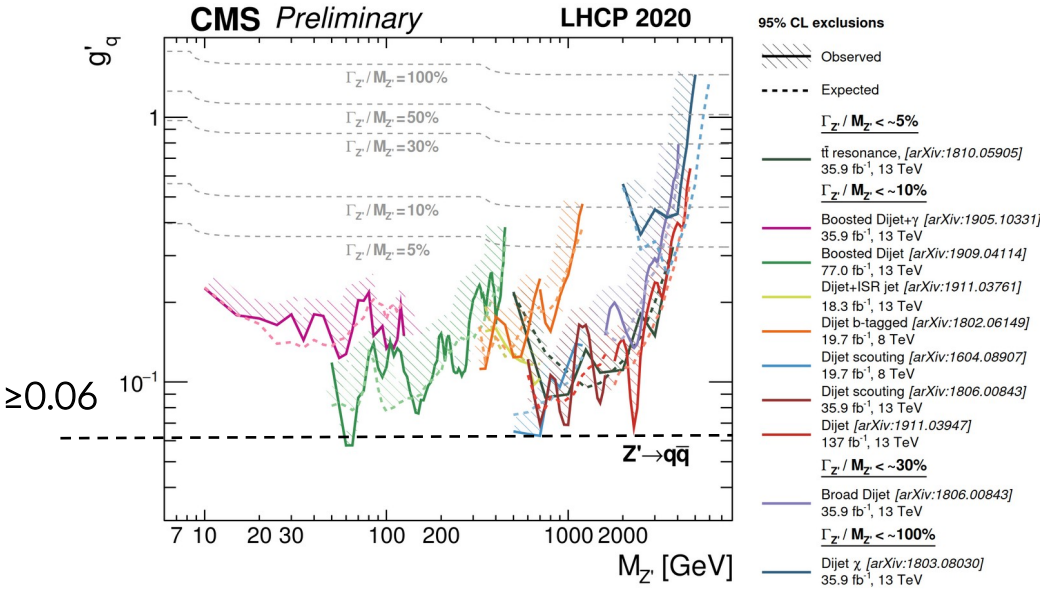


Dominant channel in benchmark case

Mediator searches provide strong constraints
especially for $m_{DM} > m_{med}/2$, but also below

Exploring the coupling dimension

Dijet: g'_q assumes BR(Z'→ qq) = 100%

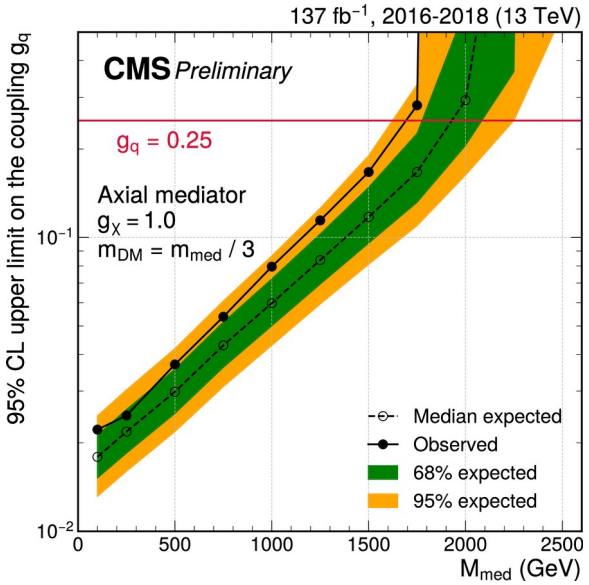


Best probes locally down to g_q'≈0.06

Many analyses to cover full mass range

BR(Z'→ DM DM) would weaken this by factor ≈ 2 → > 0.1

Monojet: g_q assumes nonzero BR to DM



Can probe down to g_q ≈ 0.02

g_q < 0.1 @ m_{med} < 1 TeV

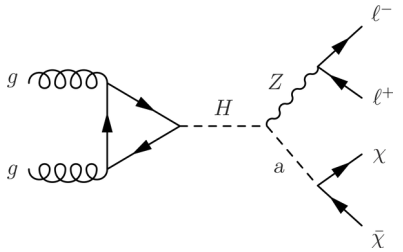
Monojet dominates in low-g_q regime if DM coupling sizable

more broadly: analysis ranking depends on parameter choice

Interactions with SM bosons

Mono-Z(ll)

Heavy Higgs H,
pseudoscalar mediator "a"

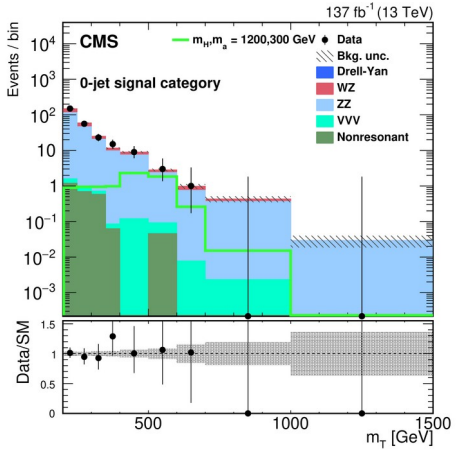


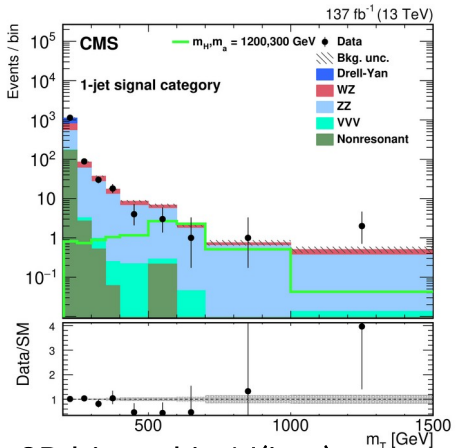
Good Z(ll) candidate
lepton triggers,
$p_T(l) > 25 / 20$ GeV
$|m(ll) - m_Z| < 15$ GeV

Moderate p_T^{miss}
$p_T^{miss} > 100$ GeV

Z and p_T^{miss} balanced, back to back
$|p_T^{miss} - p_T^{ll}| / p_T^{ll} < 0.4$
$\Delta\varphi(p_T^{miss}, p_T^{ll})$

Signal

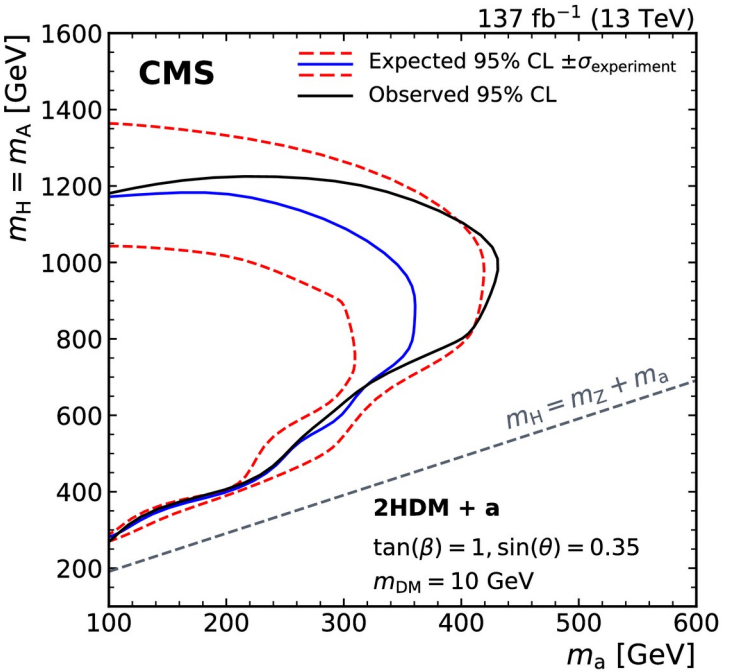




SR binned in N(jets)
→ control DY + fake p_T^{miss}

Use transverse mass as proxy for heavy Higgs mass

$$M_T^2 \to 2E_{T,1}E_{T,2}\,(1-\cos\phi)$$



In benchmark scenario:
Can probe m_H up to ≈ 1.2 TeV, m_a ≈ 400 GeV
Large additional parameter space

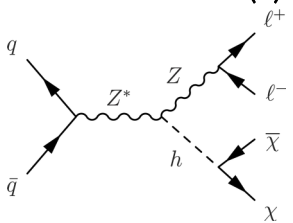
10.1140/epjc/s10052-020-08739-5

10.1016/j.physletb.2019.04.025

Higgs portal

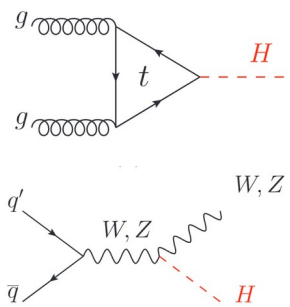
First full Run-2 results are ready

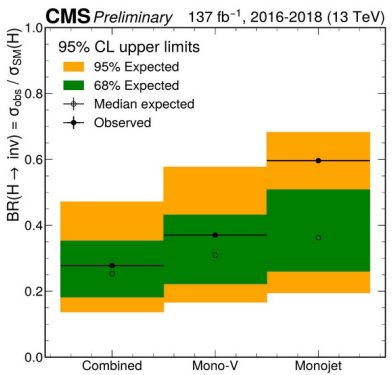
Mono-Z(ll) constrains ZH(inv)



BR(H→ inv) < 25 % (29% exp)

Monojet / -V(qq) constrains VH(inv), ggH(inv)

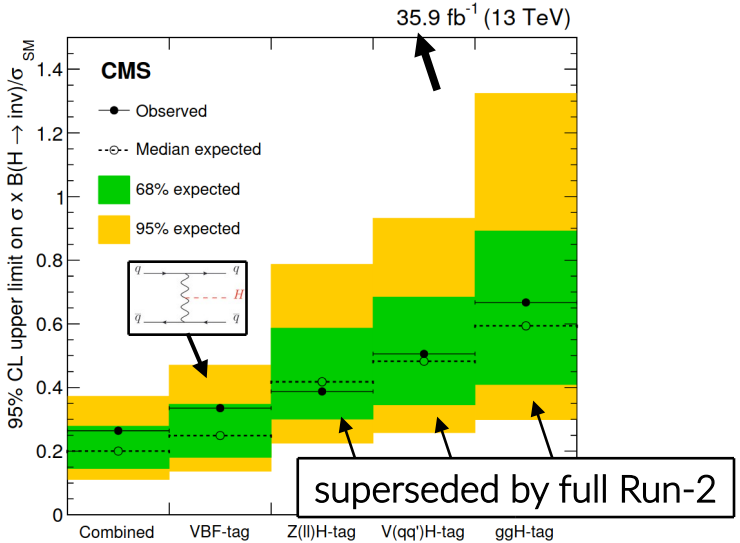




BR(H→ inv) < 28 % (25% exp)

But H(inv) is a combination game

Main driver: VBF channel



Best CMS result

Early Run-2 combination + Run-1 (8 TeV) data

BR(H→ inv) < 19 % (15% exp)

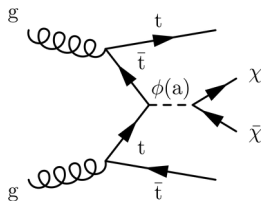
Full Run-2 combination of direct searches expected to break 10%

Many more interesting analyses in the DM orbit (list not exhaustive!)

"Standard" DM +X searches: partial Run-2 results

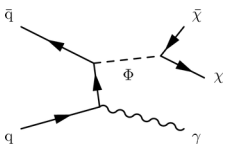
DM + top quarks

JHEP 03 (2019) 141



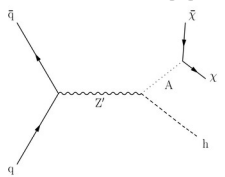
DM + photon

JHEP 02 (2019) 074



DM + Higgs

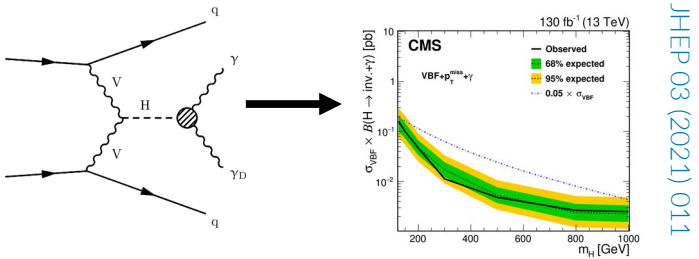
JHEP 03 (2020) 025



Extended dark sector: dark photon

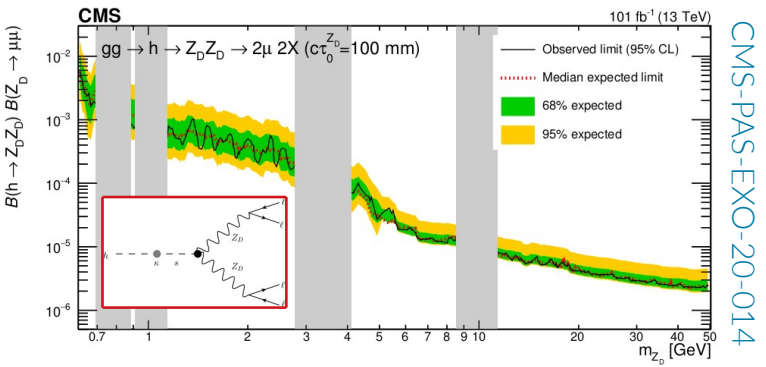
VBF H to dark photon + regular photon

JHEP 03 (2021) 011



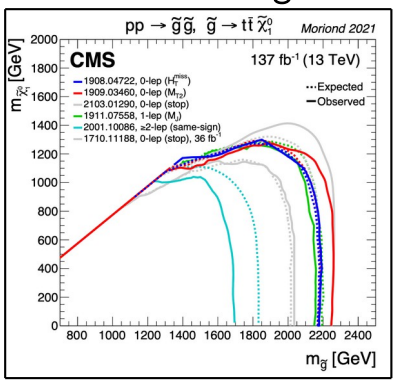
Displaced dark photon → muon decays

CMS-PAS-EXO-20-014

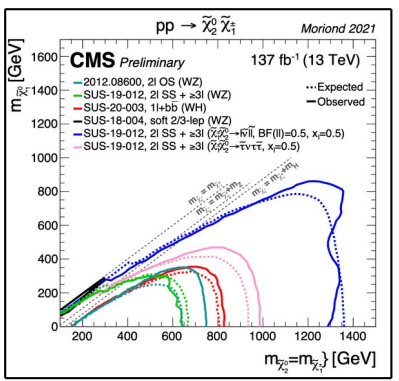


SUSY-like

from strong...



...to weak



SUSY results overview

Summary

Dark matter searches are core to CMS physics program

Wide range of probes for different types of SM-DM interactions

- DM + jet, Z, H, photon → p_T^{miss} based
- Mediator searches → visible resonances
- Dark sector → dark photons (short-lived, long-lived)

Full Run-2 data set is potent discovery tool

Strongest constraints from full data set typically in TeV range
Still plenty of additional parameter space for small couplings, etc

Partial Run-2 results soon to be updated to full Run-2 → More to come here!
All CMS results (Click)