

Search for dark matter at CMS

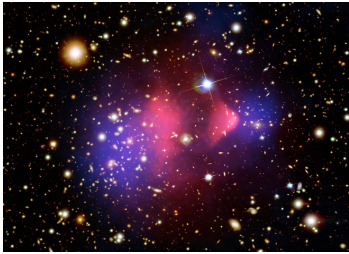
Simranjit Singh Chhibra (VUB)
On behalf of the CMS collaboration

Phenomenology 2020 Symposium, 4–6 May 2020

<https://indico.cern.ch/event/858682>

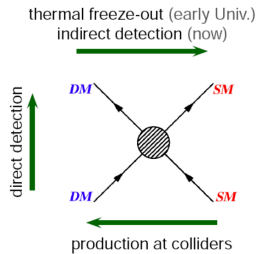
Dark matter at the LHC

DM evidence



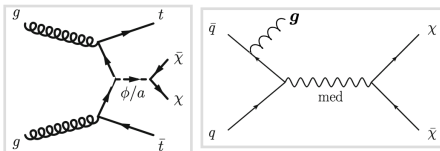
assume weak interactions with the SM

DM production



investigate specific interactions

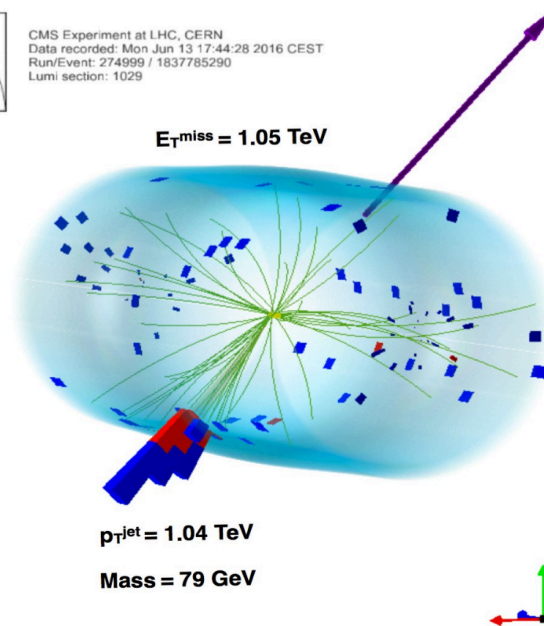
DM signatures



- **Goal: understand the origin/nature of dark matter (DM)**
- Weakly interacting DM particles **may be produced in high-energy pp collisions** at the LHC!
 - **Experimental signature:** transverse momentum imbalance (**MET or p_T^{miss}**)
 - Recoiling against standard model (SM) particles: **MET+X**
 - Several publications consider MET as key observable

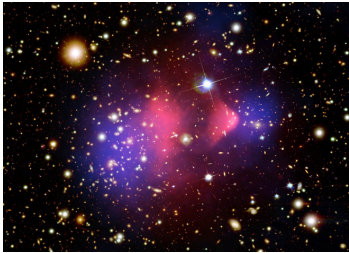


CMS Experiment at LHC, CERN
 Data recorded: Mon Jun 13 17:44:28 2016 CEST
 Run/Event: 274999 / 1837785290
 Lumi section: 1029



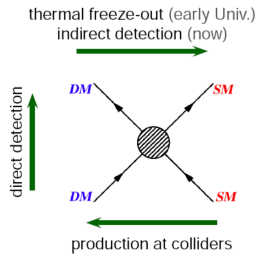
Dark matter at the LHC

DM evidence



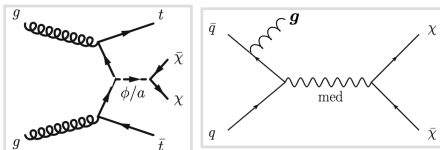
assume weak interactions with the SM

DM production



investigate specific interactions

DM signatures

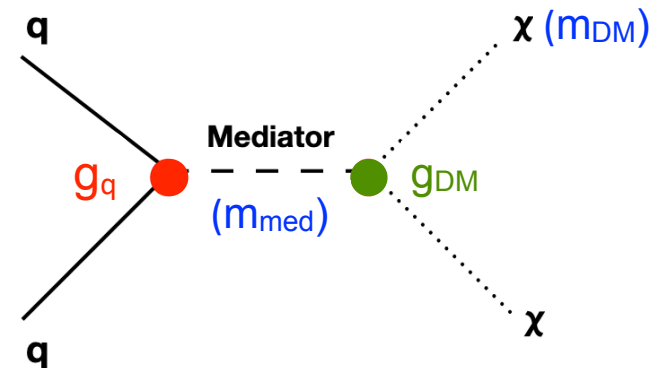


- **Goal: understand the origin/nature of dark matter (DM)**
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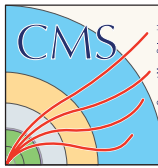
• **Searches interpreted using generic “simplified models”, with parameters:**

- spin/parity of the mediator
- Mediator mass (m_{med})
- DM mass (m_{DM})
- Mediator couplings (g_q, g_{DM})

[DM benchmark models: arXiv:1507.00966](https://arxiv.org/abs/1507.00966)



Extensive DM program at CMS



MET+X signatures

- **MET+jet**/V(qq) — 36 fb⁻¹ — [PRD 97 \(2018\) 092005](#)
- MET+Z(ll) — 36 fb⁻¹ — [EPJC 78 \(2018\) 291](#)
- MET+ γ — 36 fb⁻¹ — [JHEP 02 \(2019\) 074](#)
- MET+LQ — 77 fb⁻¹ — [PLB 795 \(2019\) 76](#)
- MET+bb — 2.2 fb⁻¹ — [EPJC 77 \(2017\) 845](#)
- **MET+tt/t** — 36fb⁻¹ — [JHEP 03 \(2019\) 141](#), [PRL 122 \(2019\) 011803](#)
- MET+t(had) — 36 fb⁻¹ — [JHEP 06 \(2018\) 027](#)
- **MET+H(bb, $\gamma\gamma$, $\tau\tau$, WW, ZZ)** — 36 fb⁻¹ — [JHEP 03 \(2020\) 025](#)
- MET+Z(ll) γ — 137 fb⁻¹ — [JHEP 10 \(2019\) 139](#)
- **VBF H(invisible)** — 36 fb⁻¹ — [PLB 793 \(2019\) 520](#)

CMS Run-2 integrated luminosity
2016: 36 fb⁻¹
2016+2017: 77 fb⁻¹
2016+2017+2018: 137 fb⁻¹

Highlighted in this talk

Visible signatures (DM interpretation)

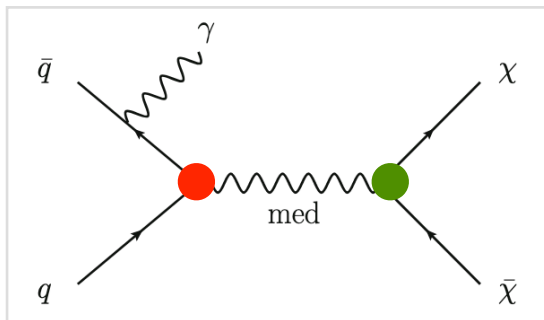
- Boosted dijet — 77 fb⁻¹ — [PRD 100 \(2019\) 112007](#)
- Dijet w/ btag — 20 fb⁻¹ (8TeV) — [PRL 120 \(2018\) 221801](#)
- Dijet w/ISR — 18 fb⁻¹ (scouting) — [arXiv:1911.03761](#)
- Dijet — 36 fb⁻¹ to 137 fb⁻¹ — [JHEP 08 \(2018\) 130](#), [arXiv:1911.03947](#)
- **4 top search** — 137 fb⁻¹ — [EPJC 80 \(2020\) 75](#)

Spin-1 mediator



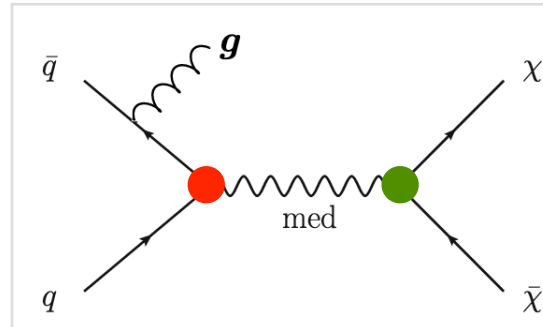
- **Signature:** DM recoils against an ISR jet/vector boson/photon

MET+photon



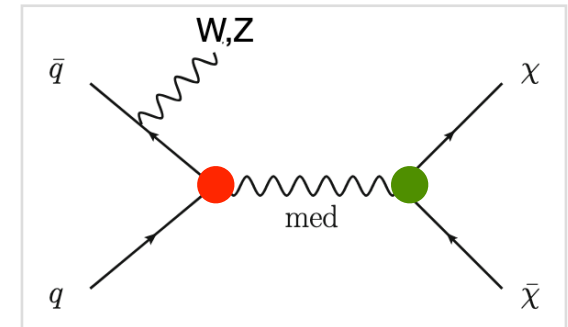
36 fb⁻¹: [JHEP 02 \(2019\) 074](#)

MET+jet



36 fb⁻¹: [PRD 97 \(2018\) 092005](#)

MET+V



36 fb⁻¹: [PRD 97 \(2018\) 092005](#)

MET+jet search

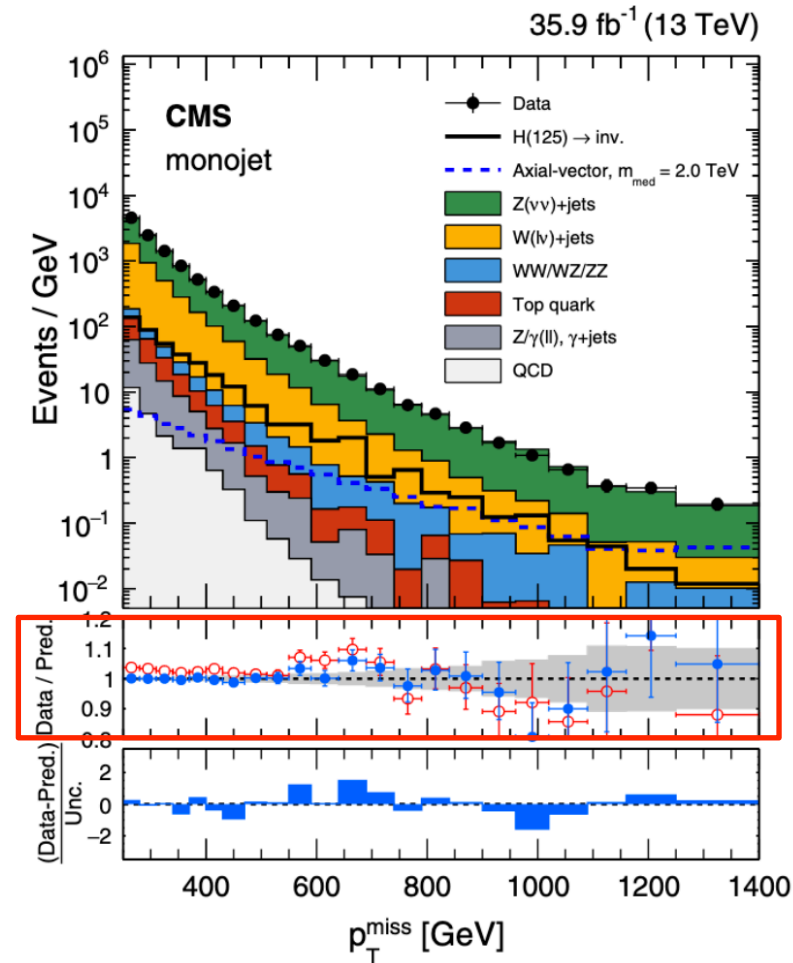
- Large cross section, typically the most sensitive final state

- Selection highlights:

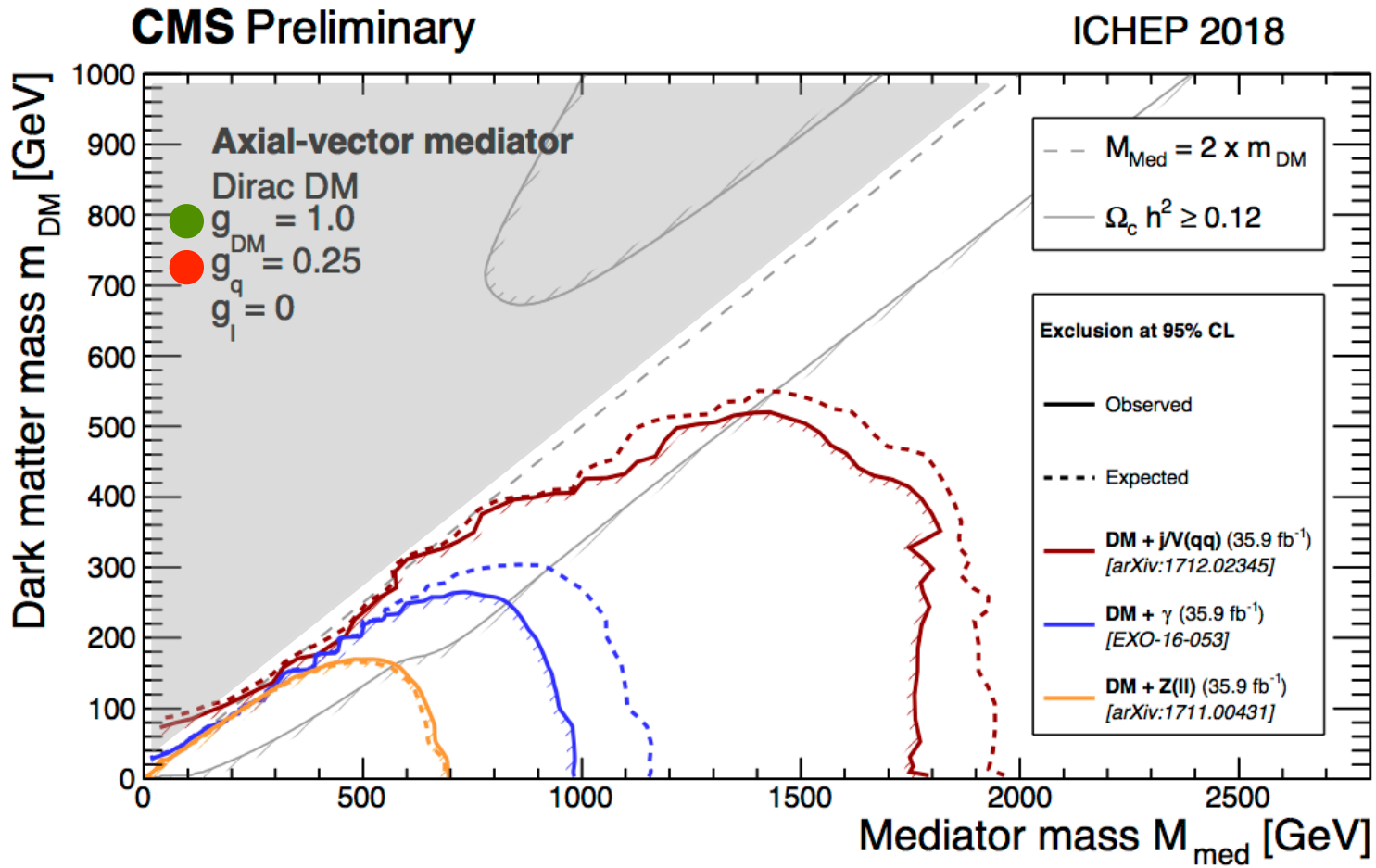
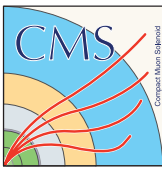
- MET > 250 GeV (cut driven by trigger)
- ≥ 1 jets with $p_T > 100$ GeV
- Lepton and b veto -> suppress top/W
- Jets and MET not aligned -> suppress QCD

- Use MET shape to extract signal

- Irreducible $Z(\nu\nu)+jets$ (~60%), $W(l\nu)+jets$ (~30%) dominant backgrounds
 - Need to precisely model the p_T spectrum
- Remarkable precision achieved using several CRs
 - A few % at MET ~250 GeV
 - ~10% in tails

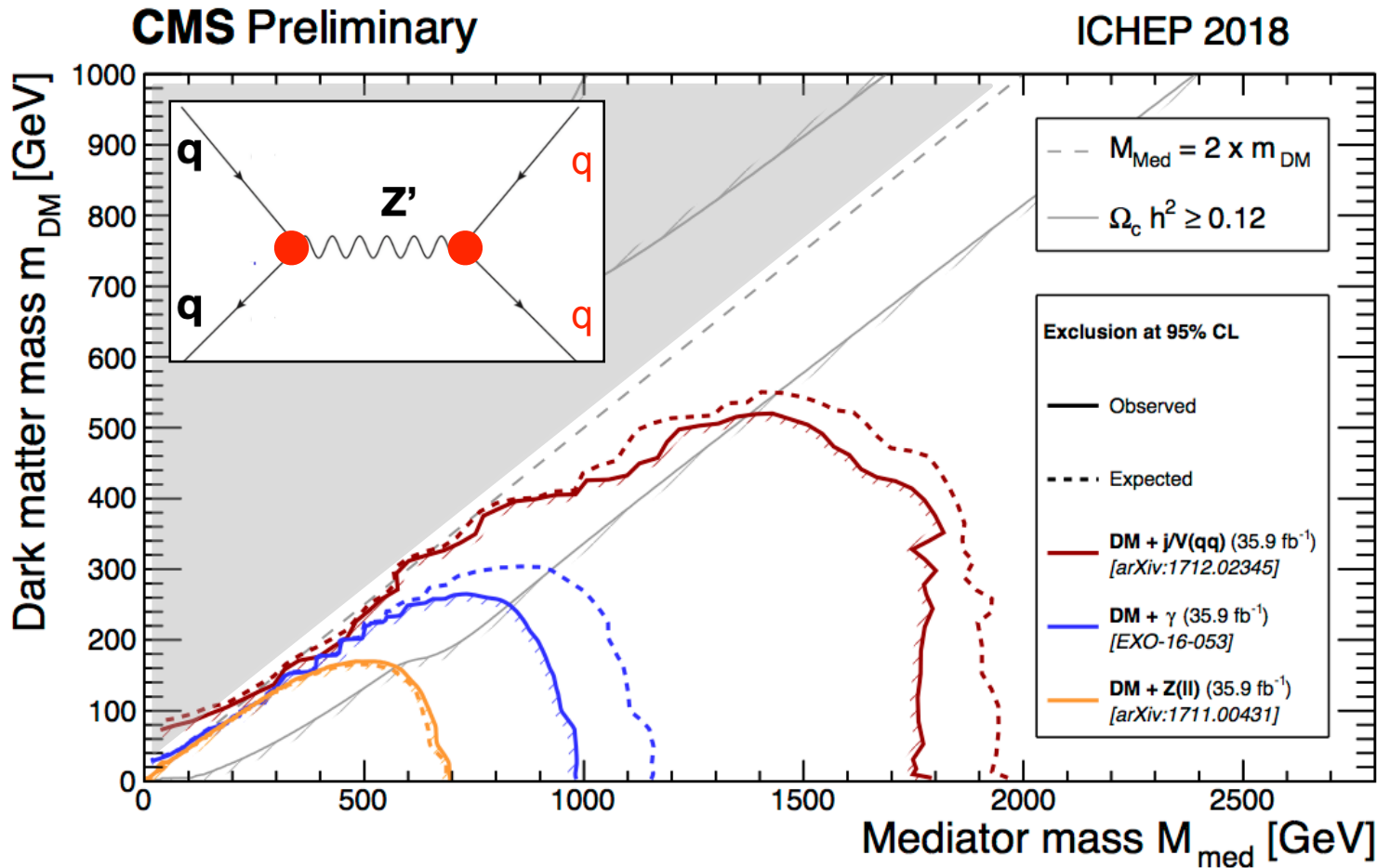
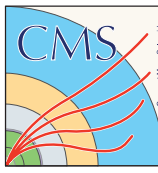


Limits for spin-1 mediator



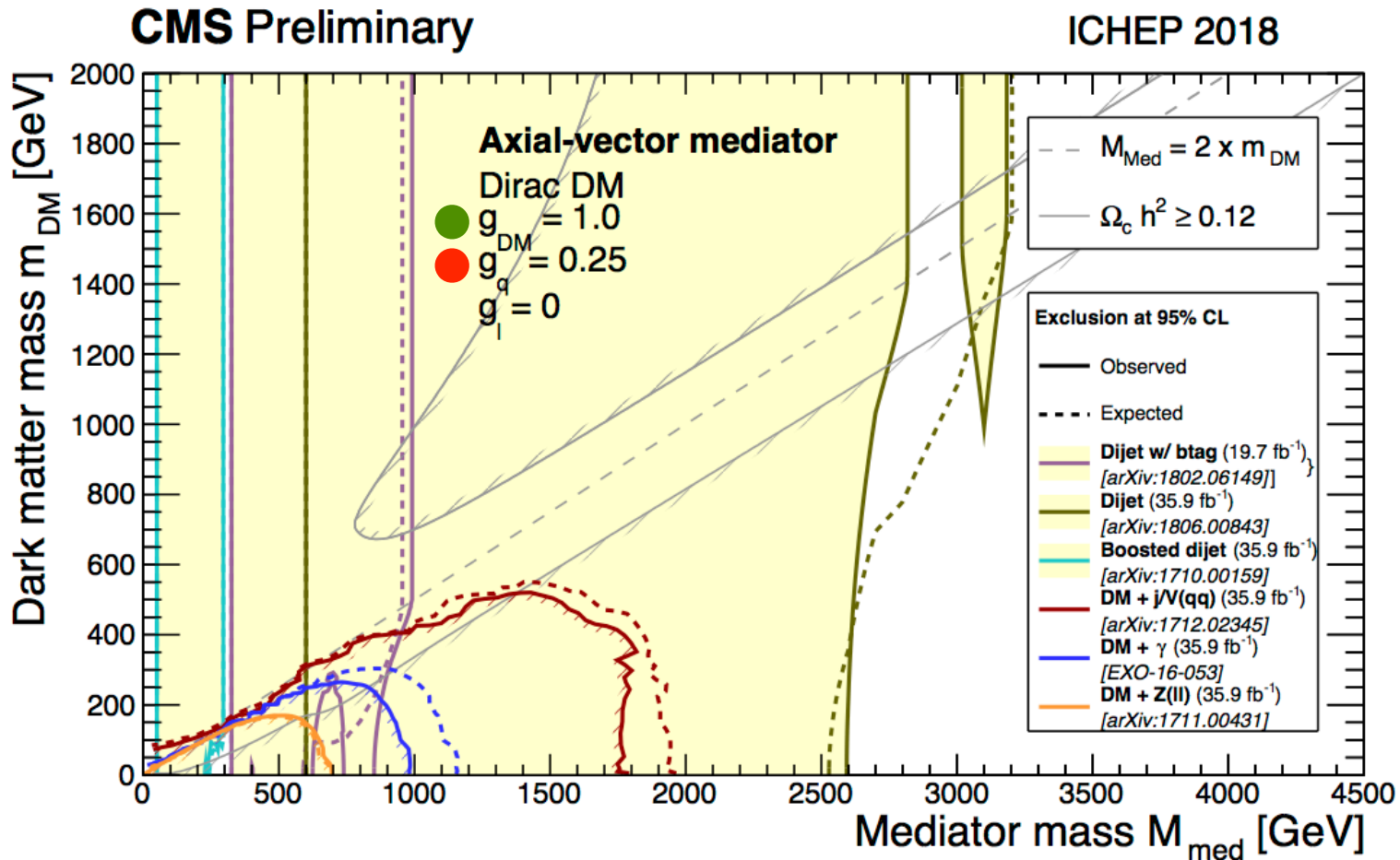
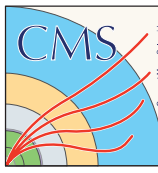
- Axial-vector mediator **masses up to 1.8 TeV** excluded
- Similar results for the vector mediator

Limits for spin-1 mediator: “the invisible through the visible”



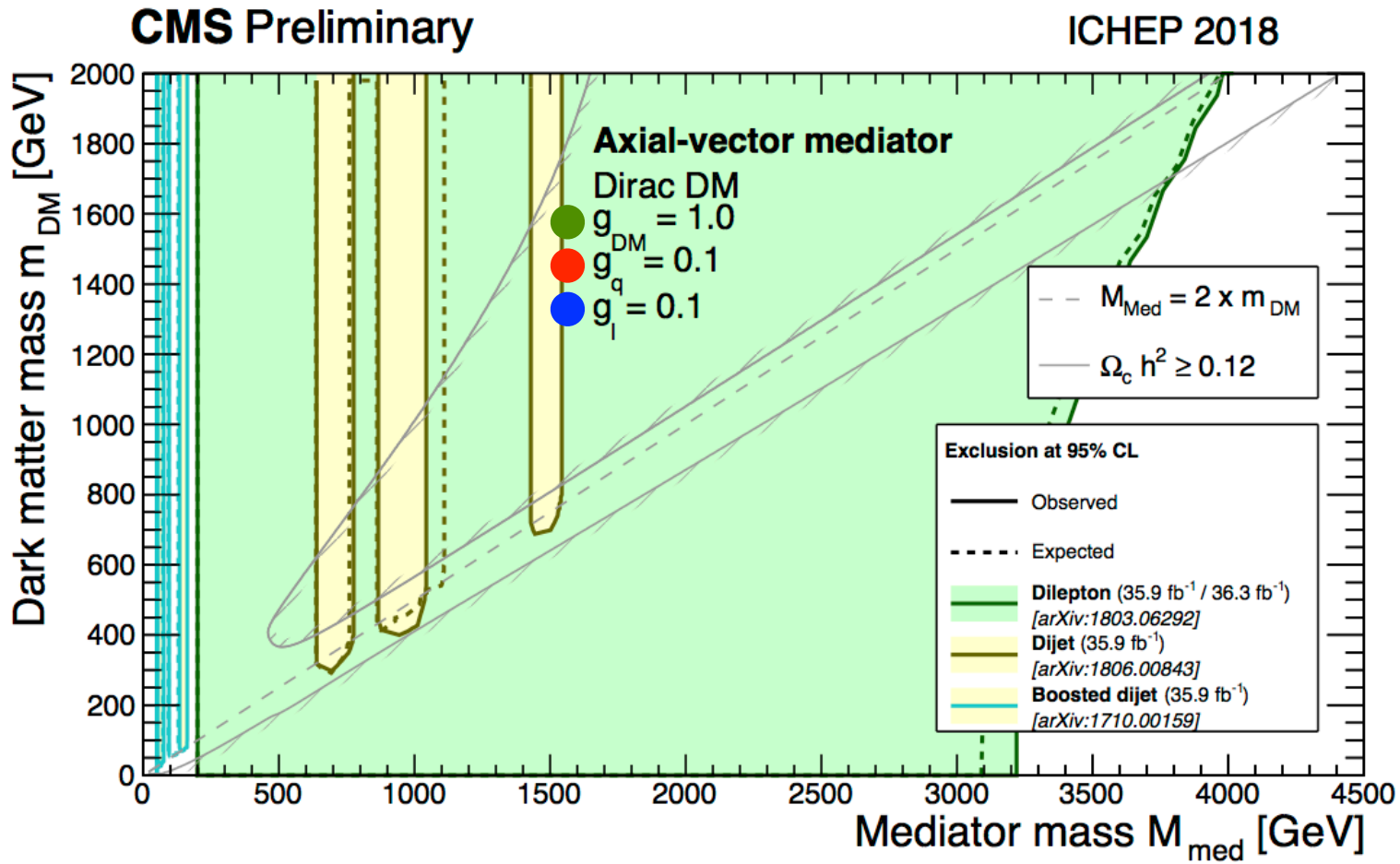
- MET+X searches not sensitive to the off-shell region ($m_{med} < 2m_{DM}$)
- Could derive constraints from searches looking for visible Z' decays

Limits for spin-1 mediator: “the invisible through the visible”



- Constraints on Z' from visible decays

Limits for spin-1 mediator: “the invisible through the visible”

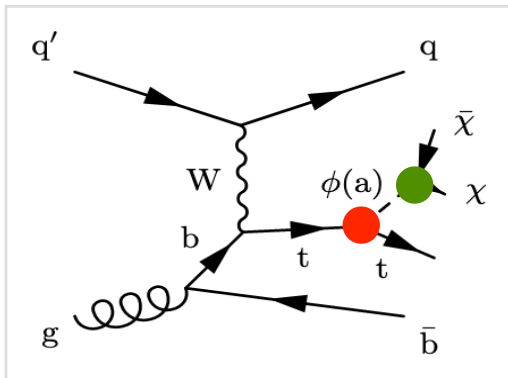


- Constraints on Z' from visible decays

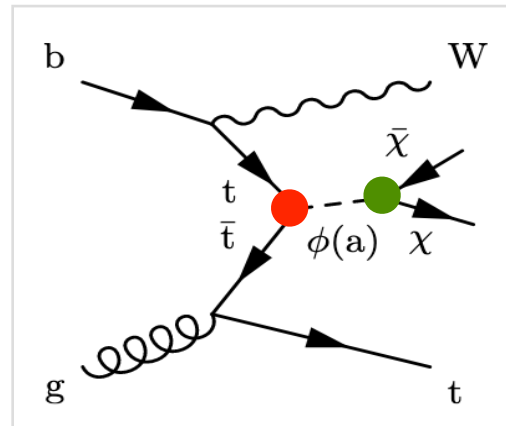
Spin-0 mediator

- Spin-0 mediator and quarks interaction required to have SM Yukawa structure
- Coupling to quarks proportional to the quark mass (like the SM Higgs boson)
- **Spin-0 mediator couples preferentially to the top quark**

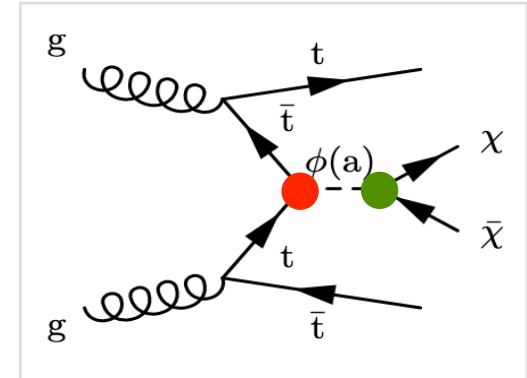
MET+t



MET+tW



MET+tt



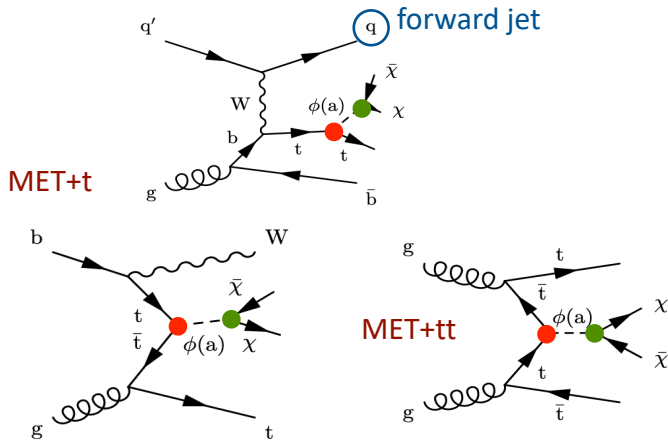
36 fb⁻¹: [JHEP 03 \(2019\) 141](#)

36 fb⁻¹: [JHEP 06 \(2018\) 027](#)

36 fb⁻¹: [PRL 122 \(2019\) 011803](#)

MET+t(tt) search

- Selection:** event categorisation based on **#leptons, #bjets and #forward jets**



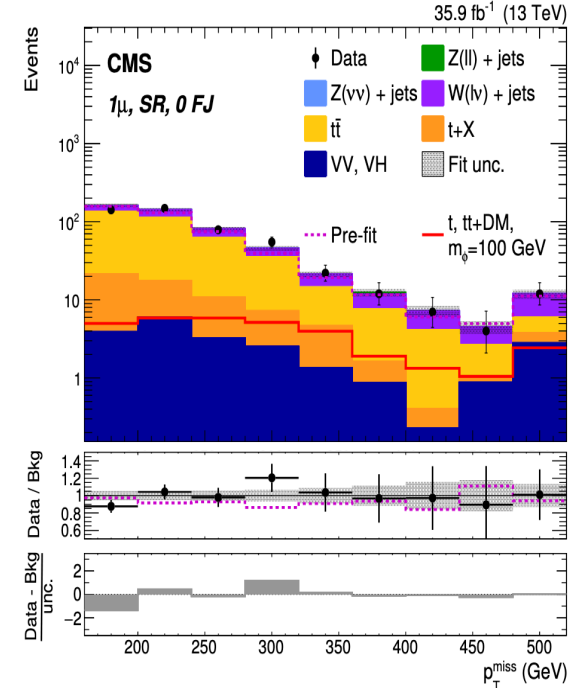
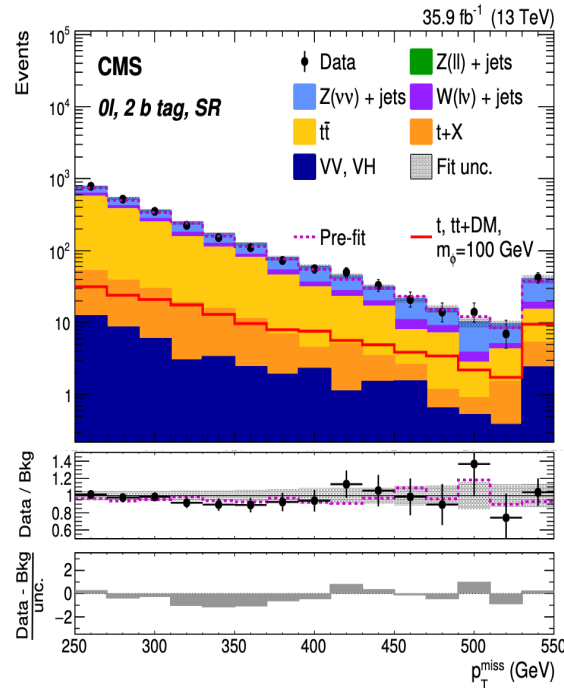
0 lepton:

- MET > 250 GeV
- e, mu veto
- >= 3 jets
- =1, >= 2 b-tagged jets
- + 0 or >= 1 forward jets ($|n| > 2.4$)

1 lepton:

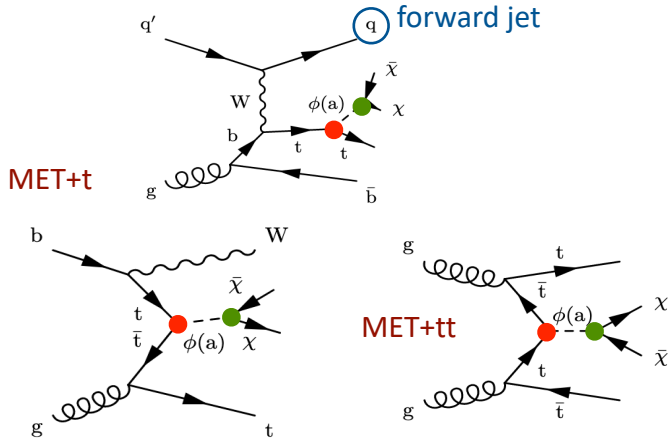
- MET > 160 GeV
- 1 isolated e/mu
- >= 2 jets
- =1, >= 2 b-tagged jets
- + 0 or >= 1 forward jets ($|n| > 2.4$)

- tt, V+jets** dominant backgrounds, from CRs
- Use MET shape to extract signal, combined fit to SRs and CRs**



MET+t(tt) search

- **Selection:** event categorisation based on **#leptons, #bjets and #forward jets**

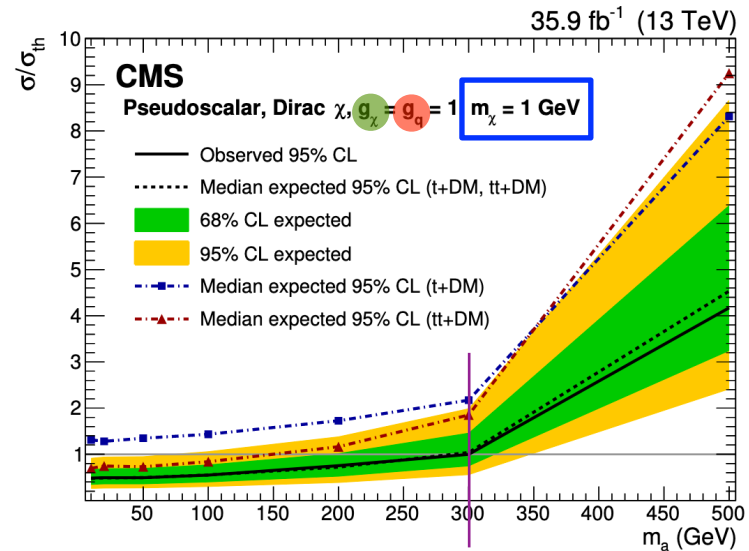
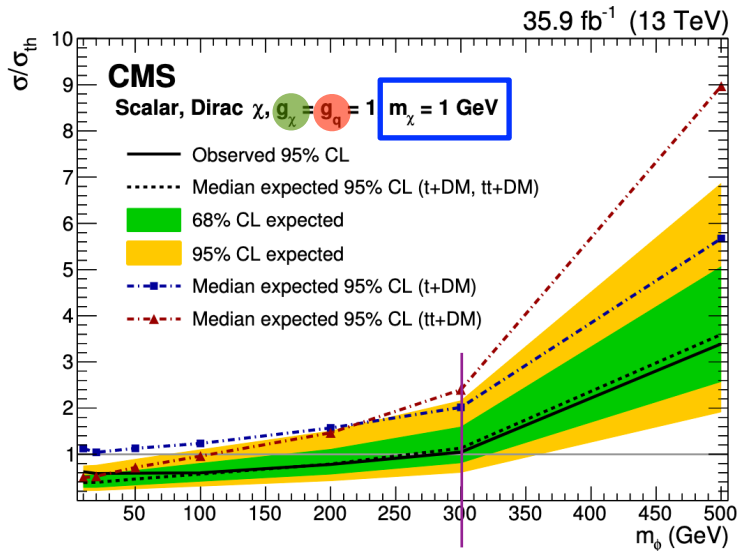


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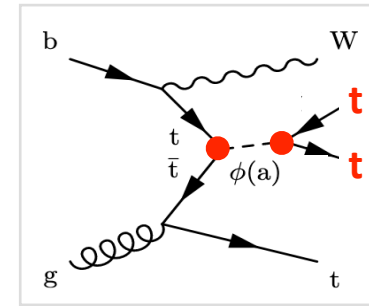
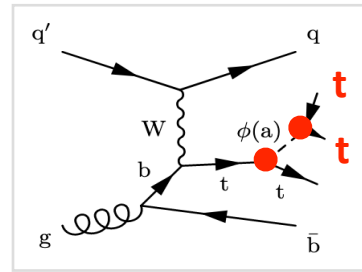
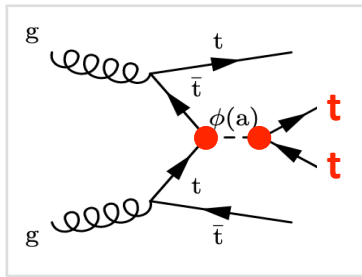
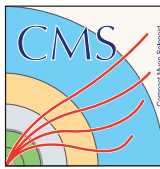
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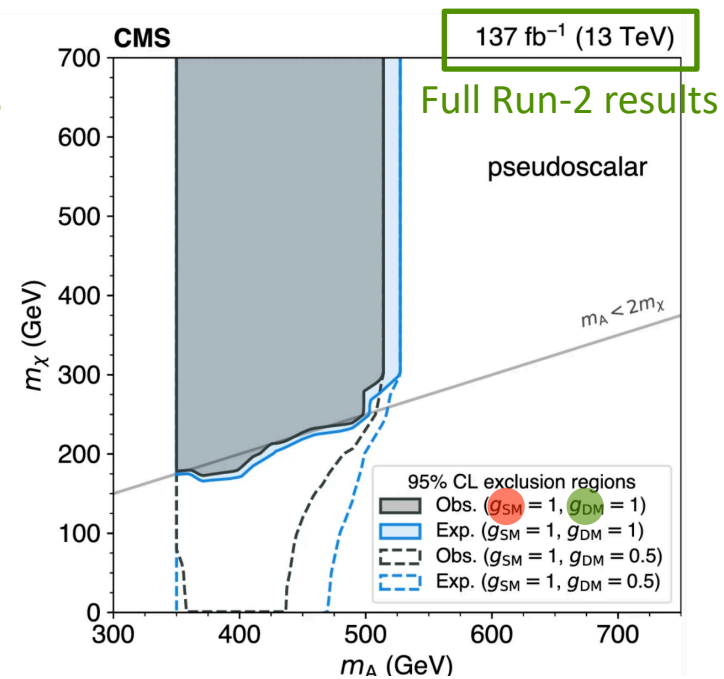
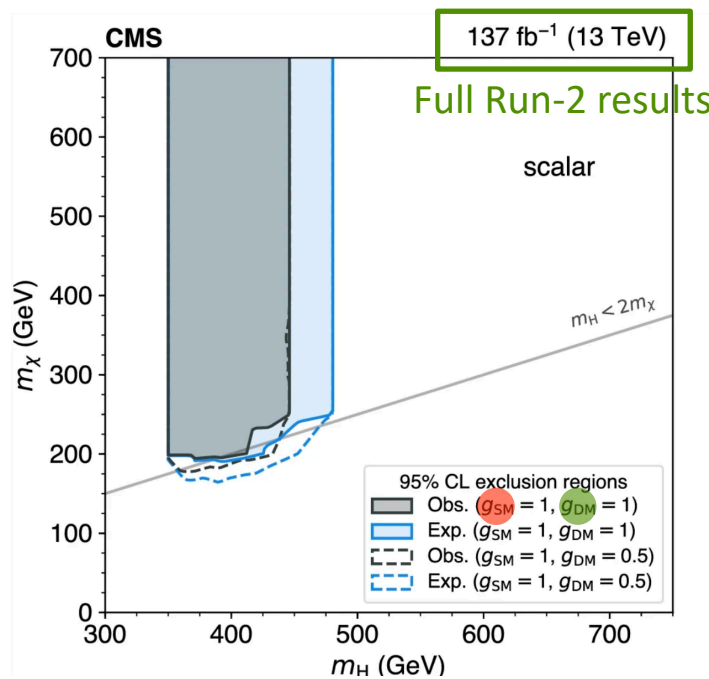


- **New results at LHC:** up to 2x better limits at high mediator masses wrt MET+tt limits only

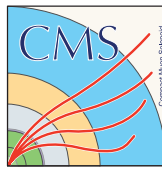
Spin-0 interactions: “the invisible through the visible”



[DM interpretation: EPJC 80 \(2020\) 75](#)

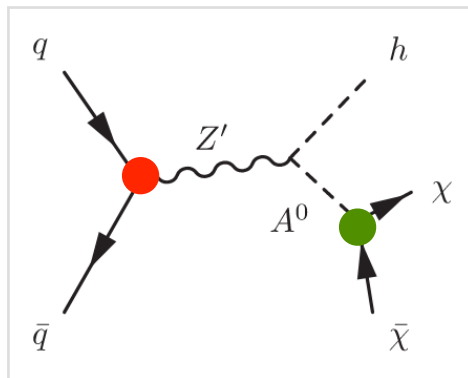


Higgs: extended sectors and invisible decays



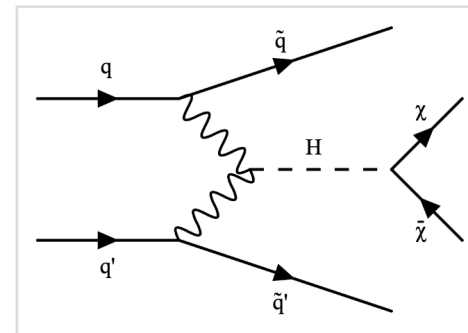
- **Signature:** large MET and one Higgs boson candidate

MET+H125



36 fb⁻¹: [JHEP 03 \(2020\) 025](#)

VBF H125(invisible)

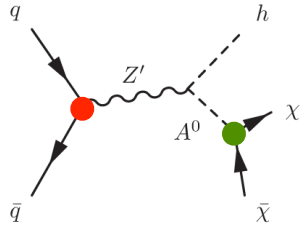


36 fb⁻¹: [PLB 793 \(2019\) 520](#)

MET+H(bb)

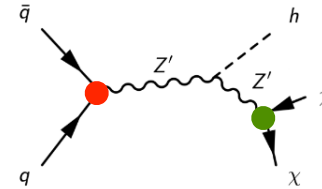
- **Selection:** different approach based on **Higgs boson boost**

Z'-2HDM: 2HDM + Z' (hA),
 “resonant” to Z' mass (**large boost**)

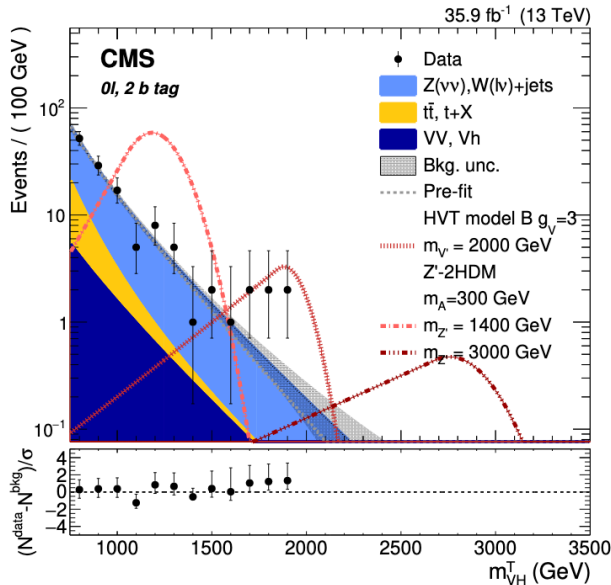


- 1 jet with $p_T > 200$ GeV
- 1, 2 b-tagged jets
- Jet invariant mass in m_H range

Baryonic Z': Z' radiates a Higgs and
 decays to DM, “non-resonant” (**medium boost**)



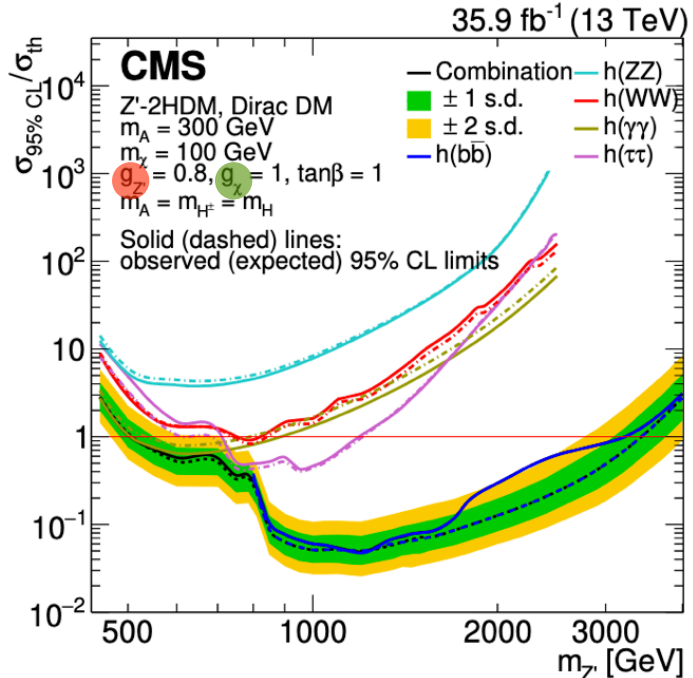
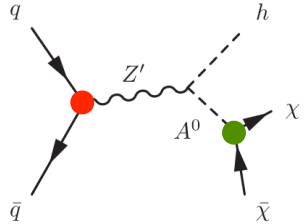
- Similar approach as of large boost, but with “larger cone” to reconstruct the jet



- **V+jets, tt** dominant backgrounds, from CRs
- **Combined fit of SRs and CRs**
 - $m_T(\text{MET}, H)$ for large boost
 - MET for medium boost

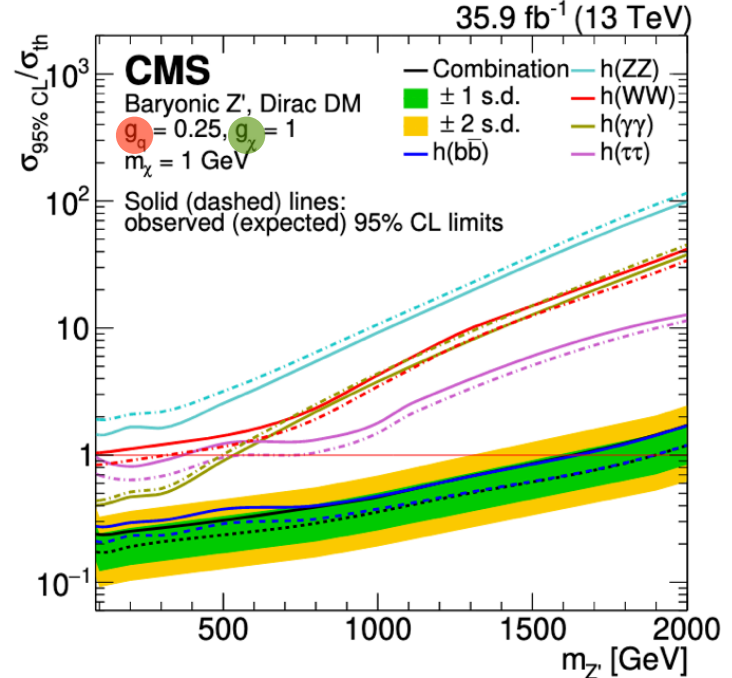
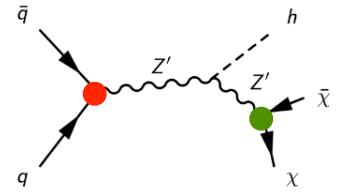
DM+H(bb, $\gamma\gamma$, $\tau\tau$, WW, ZZ)

Z'-2HDM: 2HDM + Z'(hA),
 "resonant" to Z' mass (**large boost**)



500 < m_{Z'} < 3200 GeV
excluded for m_A = 300 GeV

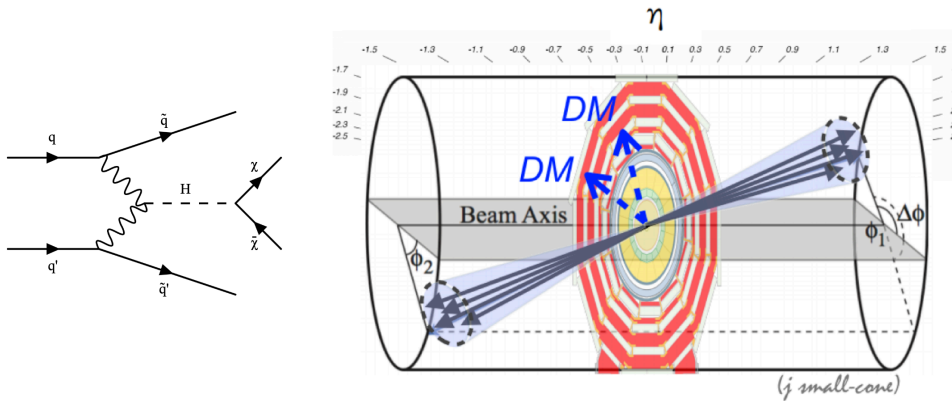
Baryonic Z': Z' radiates a Higgs and
 decays to DM, "non-resonant" (**medium boost**)



100 < m_{Z'} < 1600 GeV
excluded for m_χ = 1 GeV

VBF H(invisible)

- Most sensitive channel to look for H(invisible)

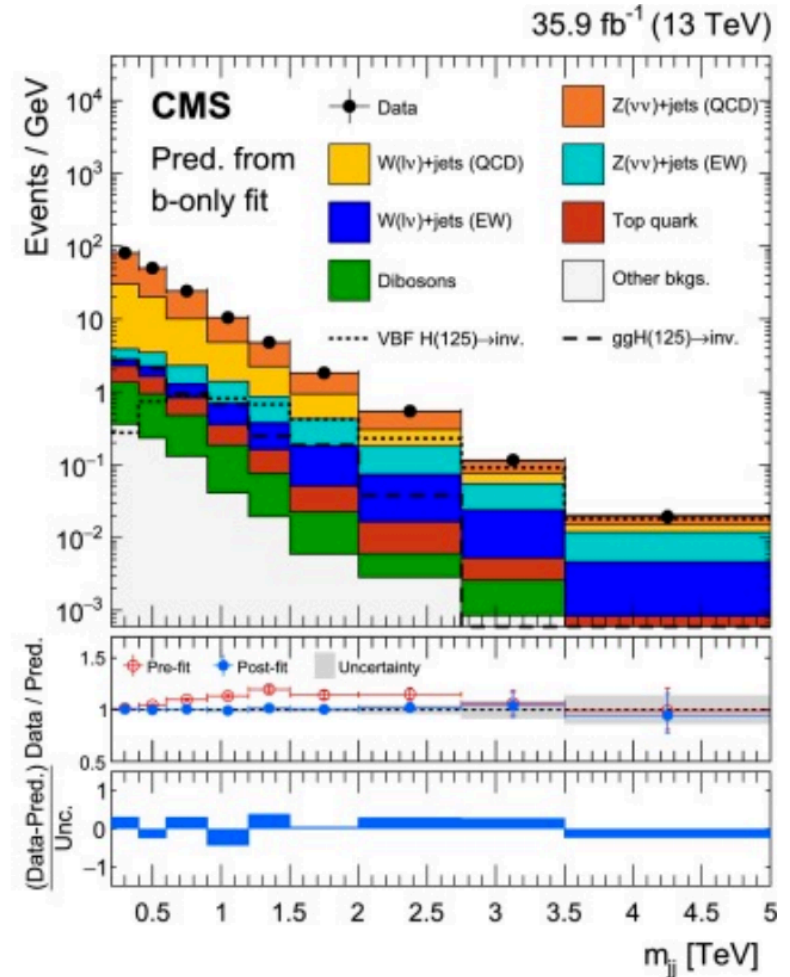


• Selection highlights:

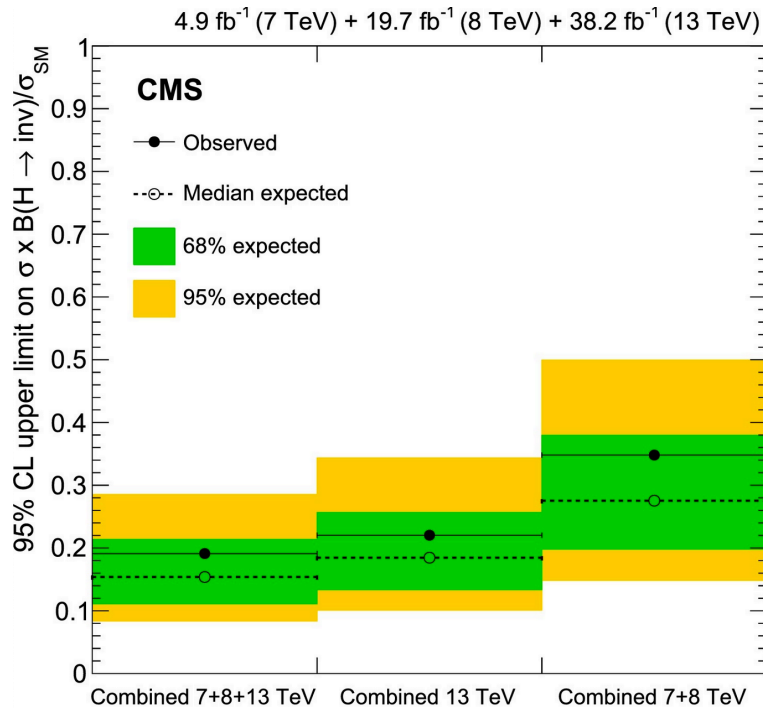
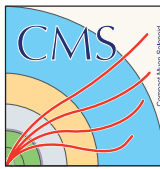
- 2 jets with $\Delta\eta(jj) > 1.0$ and $\Delta\phi(jj) < 1.5$
- $pt(j_1) > 80$ GeV and $pt(j_2) > 40$ GeV
- $MET > 250$ GeV
- Lepton veto -> suppress W/top

- $Z(\nu\nu)+jets$, $W(l\nu)+jets$ dominant backgrounds

- Fit to m_{jj} spectrum

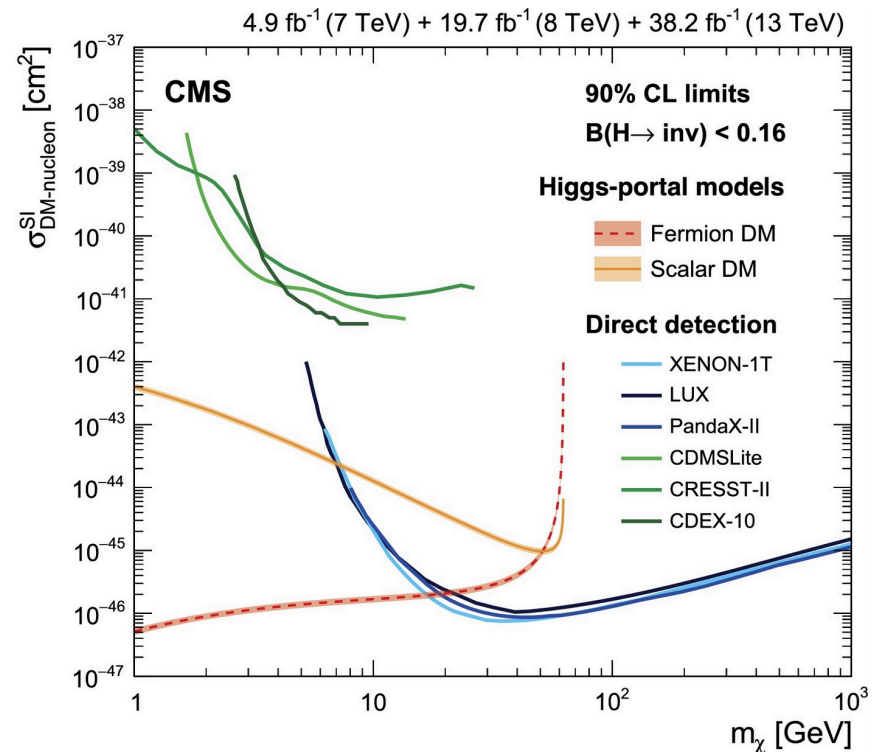


H(invisible)



BR of H(invisible) < 0.19 (0.15)
obs. (exp.) at 95% CL

Spin-independent DM-nucleon elastic scattering cross section limits



Summary



- **Dark matter is a main goal at the LHC!**
- **Extensive, on-going MET+X program at CMS!**
 - Various interactions and signatures investigated
 - Very competitive results if mediator can be produced on-shell and/or DM is light
 - Essential complementarity with visible searches to investigate larger regions of parameter space of DM models
- **No signs of excess in data so far**
- **Mostly only 2016 data (36 fb⁻¹) analysed so far at 13 TeV**
- **Many new results expected with full 2016+2017+2018 data (137 fb⁻¹)**

Stay tuned!

Thank you for your attention!