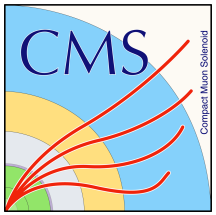


Searches for new physics in events with leptons in the final state in CMS

Jie Xiao (Peking University)
on behalf of the CMS collaborations

The 7th China LHC Physics Workshop (CLHCP2021)
25-28 November 2021

Outline

Many new physics models are expected to manifest themselves in the final state with leptons. This talk presents searches in CMS for new phenomena in the final state that includes leptons, focusing on the recent results obtained using the full Run-II data-set collected at the LHC in following areas:

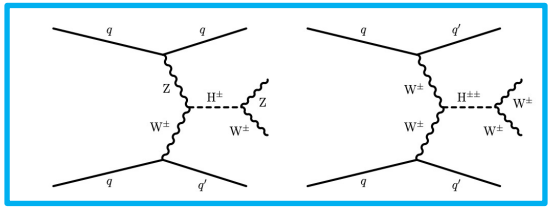
- The Higgs Sector
- Exotic Heavy Resonance
- Exotic Dark Matter
- Majorana neutrino

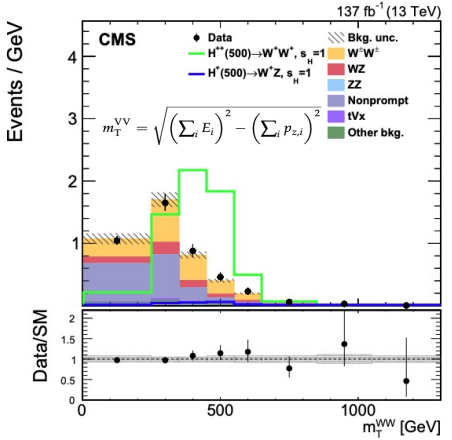
The Higgs Sector

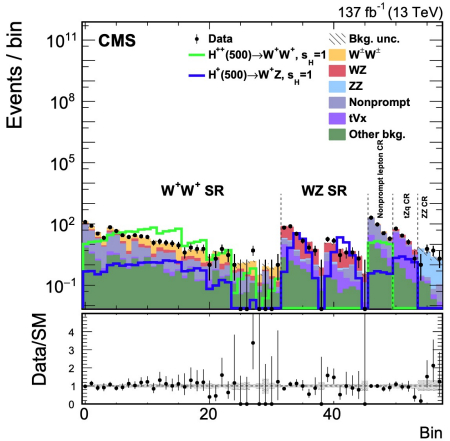
Search for VBF $H^{\pm}$ and $H^{\pm\pm}$

Eur. Phys. J. C 81 (2021) 723

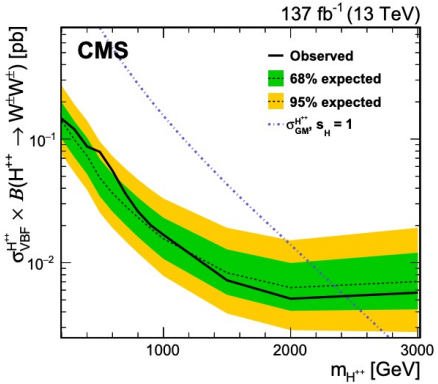
- In **Georgi-Machacek model**, extended Higgs sectors give rise to **charged Higgs bosons** with couplings to W and Z
- Search for **VBF $H^{\pm\pm} \rightarrow W^{\pm}W^{\pm}$ and $H^{\pm} \rightarrow W^{\pm}Z$** in fully leptonic ($e/\mu$) decays
- Main backgrounds: **diboson**, **non-prompt lepton**
- **m_T^{VV}** and **m_{jj}** effective in **discriminating** between signal and background



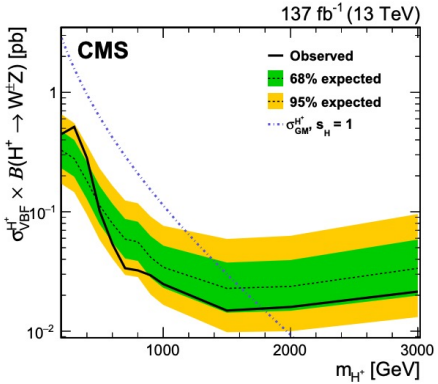




Expected and observed exclusion limits at 95% CL



$\sigma_{VBF}(H^{\pm\pm})\,\mathcal{B}(H^{\pm\pm} \rightarrow W^{\pm}W^{\pm})$



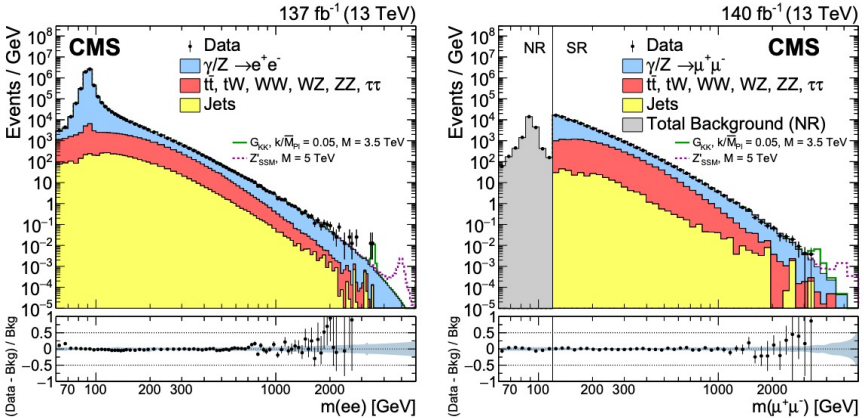
$\sigma_{VBF}(H^{\pm})\,\mathcal{B}(H^{\pm} \rightarrow WZ)$

Exotic Heavy Resonance

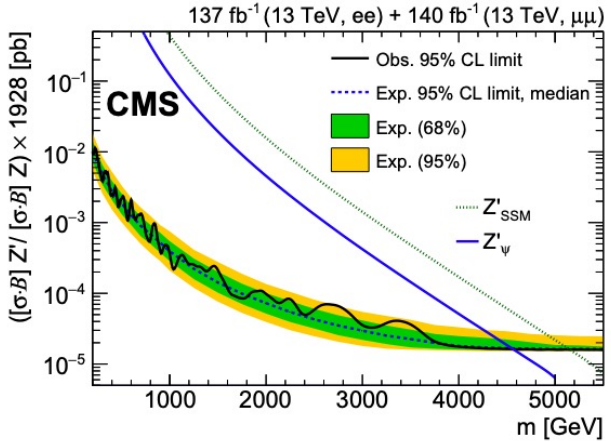
Di-Lepton Resonances

JHEP 07 (2021) 208

- Simple signature: **Z' → ll**
- Multiple theory models
  - E.g., Spin-1 resonances in a sequential **SM (SSM)** and a superstring-inspired model: **Z'_{SSM}** or **Z'_{ψ}**
- Lepton backgrounds from high order simulation with Z peak used to normalize. Jet backgrounds estimated from data



ee channel **μμ channel**



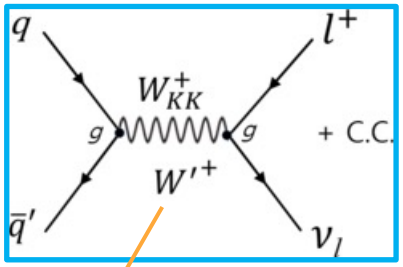
Limits for a spin-1 narrow resonance with an intrinsic width of 0.6%

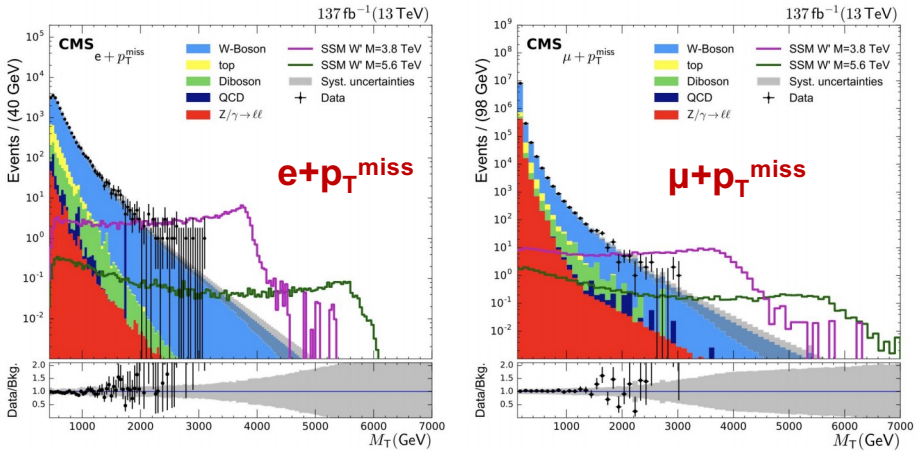
Lepton + MET Resonances

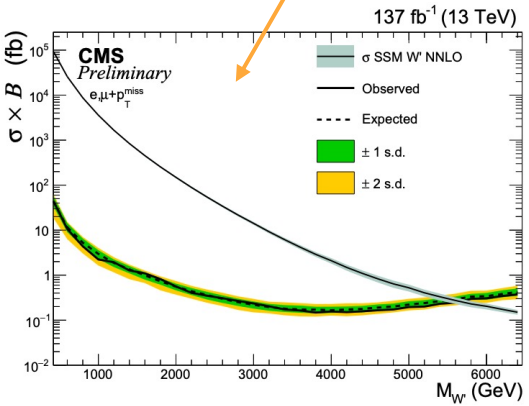
CMS-PAS-EXO-19-017

- **W' → lν** : high pT lepton and "nothing else" (pT miss), inclusive in number of jets
  - Equivalent **SSM** interpretation
  - Split-Universal Extra Dimension (**split-UED**) model, Kaluza-Klein (KK) partner: $W_{KK}^{(n)}$
- Study based on a binned fit in the discriminant variable $\mathbf{M_T}$

$$M_{\mathrm{T}} = \sqrt{2p_{\mathrm{T}}^{\ell}\ p_{\mathrm{T}}^{\mathrm{miss}}\left(1-\cos[\Delta\phi(\ell,\vec{p}_{\mathrm{T}}^{\mathrm{miss}})]\right)}$$





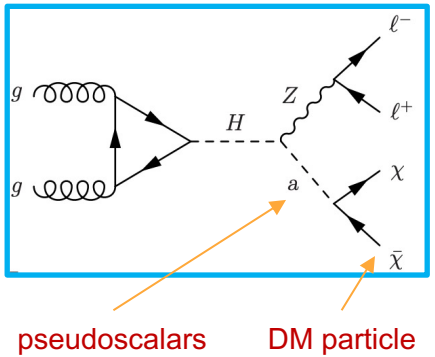


Exotic Dark Matter

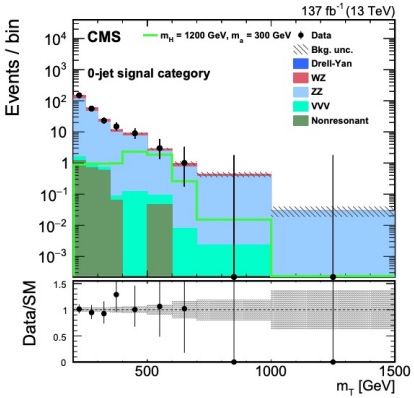
Dark matter produced in association with Z boson

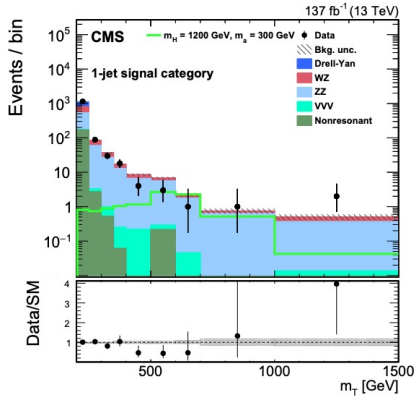
EPJC 81 13 (2021)

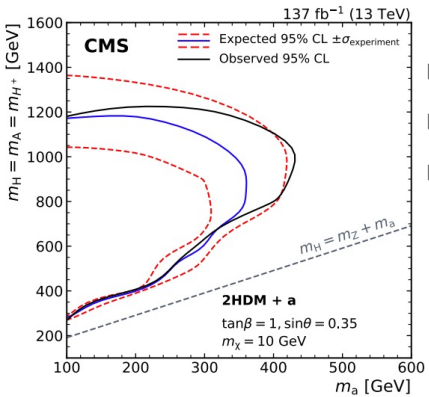
- Several models are considered including Two-Higgs-doublet model + pseudoscalars (**2HDM+a**), **simplified DM**, **invisible Higgs** and **Graviton**
- **"mono-Z"** scenario: a Z boson produced in pp collisions, recoils against **DM** or other **BSM invisible particles**
- Baseline selections require same flavor oppositely charged lepton pair within Z mass window, (b)-jet veto and additional lepton veto, and p_T^{miss} and m_T
- Fit either $\mathbf{p_T^{miss}}$ or $\mathbf{m_T}$ distribution to data ($\mathbf{m_T}$ is used for **2HDM+a**)



$$m_T = \sqrt{2 p_{\ell\ell}^T p_T^{miss} [1 - \cos \Delta\phi(\vec{p}_T^{\ell\ell}, \vec{p}_T^{miss})]}$$







- Categorize the signal regions by **0 or 1 jet**
- Limits are set on the $\mathbf{m_a}$ at 95%
- $\mathbf{m_a}$ up to 440 GeV is excluded for m_H=1 TeV

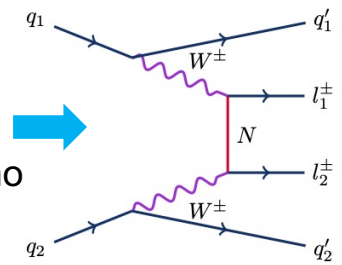
Majorana neutrino

Majorana neutrinos in VBF production of same-sign muons

- Neutrino mass is an interesting topic, not included in standard model (SM), observed in experiments
- Many ways to explain $m_\nu \neq 0$: the neutrinos may be either Dirac or Majorana fermions
- Possible **neutrinoless** ββ process (**0νββ**) at colliders, **Vector Boson Fusion (VBF) process: pp → ℓ±ℓ±jj**

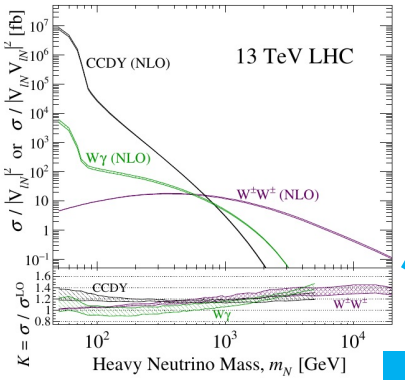
Phys. Rev. D **103**, 055005

Type-I See-Saw
heavy Majorana Neutrino



Mixing matrix

$$V_{lN} = \begin{pmatrix} V_{eN_1} & V_{eN_2} & V_{eN_3} \\ V_{\mu N_1} & V_{\mu N_2} & V_{\mu N_3} \\ V_{\tau N_1} & V_{\tau N_2} & V_{\tau N_3} \end{pmatrix}$$



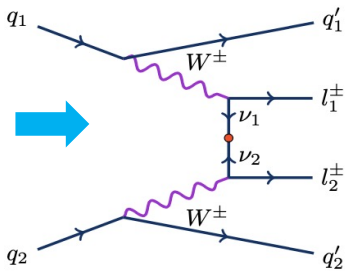
Ongoing

Phys. Rev. D 103, 115014

The EFT approach
The Weinberg operator

$$\mathcal{L}_5 = \frac{C_5^{\ell\ell'}}{\Lambda}\left[\Phi\cdot\overline{L}_\ell^c\right]\left[L_{\ell'}\cdot\Phi\right]$$

Flavor dependent wilson coef.
SM left-hand leptons
SM Higgs doublet
Effective Field Theory Scale



Analysis in CMS:
EXO-21-003

Summary and Outlook

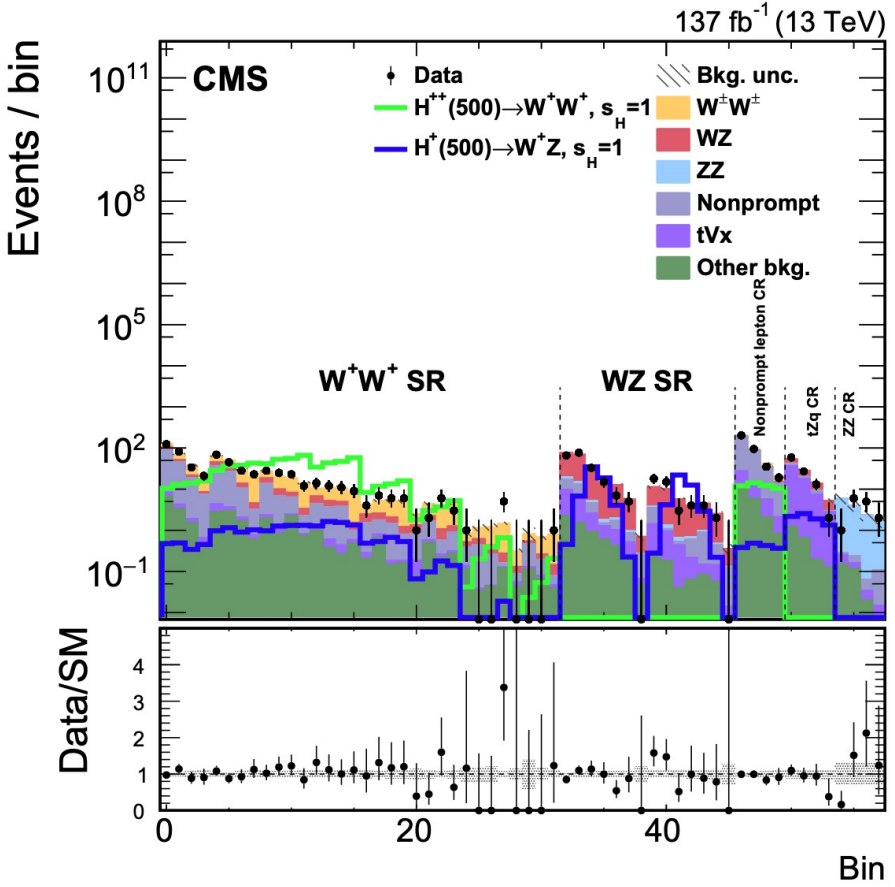
- CMS is highly active in BSM searching with leptons
- Many BSM models are explored, e.g., the Higgs sectors, exotic heavy resonances, extra dimensions, and dark sector extensions, …
- No significant deviation from SM expectation is observed
- Still many degrees of freedom left to explore, many works in progress …

Backup

Search for VBF $H^{\pm}$ and $H^{\pm\pm}$

CMS-PAS-HIG-20-017

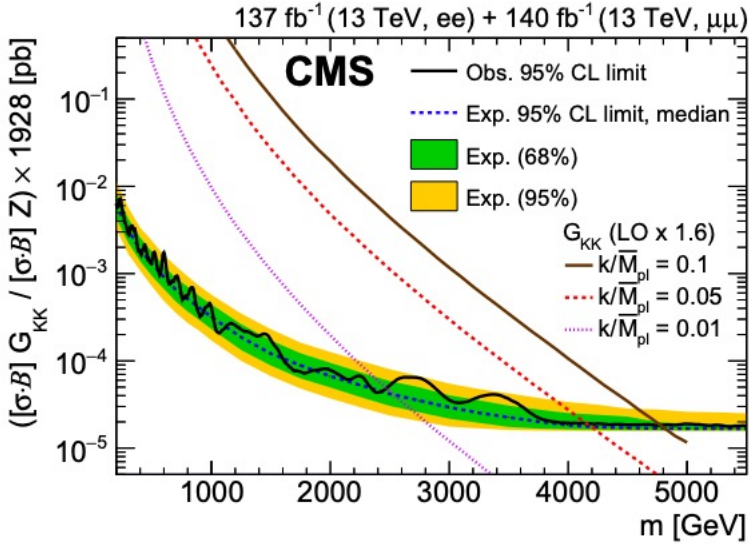
- $W^{\pm}W^{\pm}$ SR (2D)
  - 8 bins in m_T^{VV} ([0, 250, 350, 450, 550, 650, 850, 1050, ∞]
  - 4 bins in m_{jj} ([500, 800, 1200, 1800, ∞] GeV)
- WZ SR (2D)
  - 7 bins in m_T^{VV} ([0, 325, 450, 550, 650, 850, 1350, ∞] GeV)
  - 2 bins in m_{jj} ([500, 1500, ∞] GeV)
- CRs
  - 4 bins in m_{jj} ([500, 800, 1200, 1800, ∞] GeV)



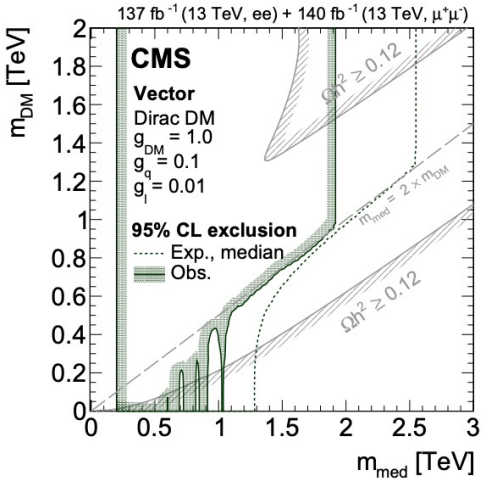
Di-Lepton Resonances

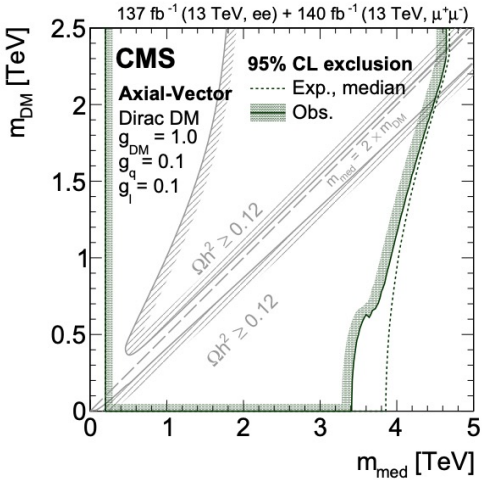
CMS-EXO-19-019

Upper limits for **a spin-2 graviton** resonances in the **Randall–Sundrum model** of extra dimensions



Exclusion limits in the mass plane of the **mediator** and **DM particles**

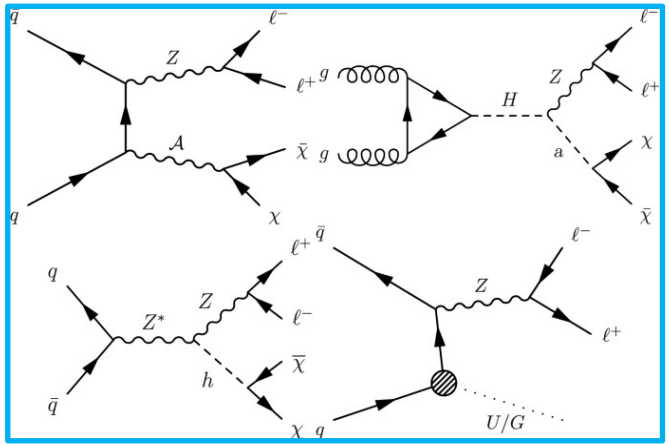


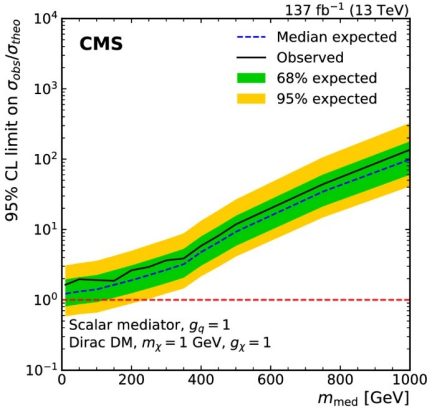


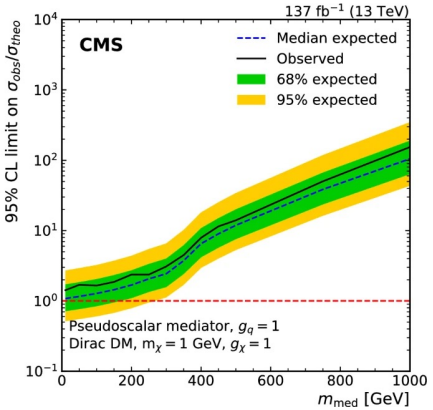
Dark matter produced in association with Z boson

EPJC 81 13 (2021)

- Several models are considered including Two-Higgs-doublet model + pseudoscalars (**2HDM+a**), **simplified DM**, **invisible Higgs** and **Graviton**







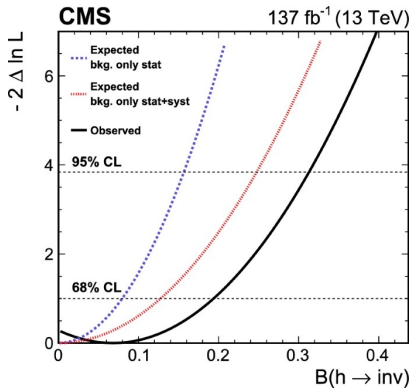
- 95% CL upper limits on the cross section for simplified DM models with scalar (upper) and pseudoscalar (lower) mediators.
- The coupling to quarks is set to g_q=1, the coupling to DM is set to g_χ=1 and the DM mass is $m\chi$=1GeV

Dark matter produced in association with Z boson

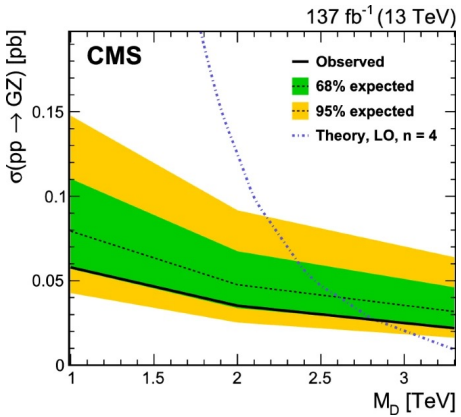
EPJC 81 13 (2021)

- Several models are considered including Two-Higgs-doublet model + pseudoscalars (**2HDM+a)**, **simplified DM**, **invisible Higgs** and **Graviton**

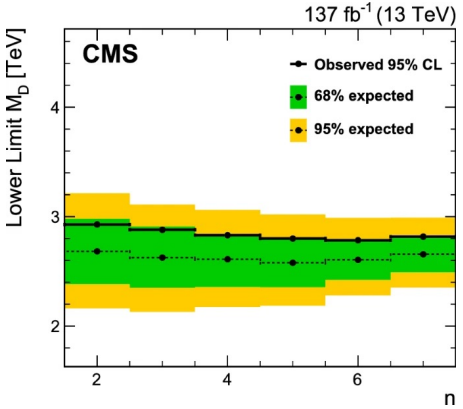
- Upper limits of branching fraction of the Higgs boson invisible decay



- The 95% CL cross section limit in the ADD* scenario as a function of M_D for n=4



- 95% CL expected and observed exclusion limits on M_D as a function of the number of extra dimensions *n*



***Arkani-Hamed–Dimopoulos–Dvali (ADD)** model of large extra dimensions. which is motivated by the disparity between the electroweak (EW) unification scale and the Planck scale. This model predicts graviton (G) production

Lepton + MET Resonances

CMS-PAS-EXO-19-017

- **Cross-section limits** set as a function of transverse mass
- In **split-UED** model, **R** (the extra dimension radius) vs. **μ** (the bulk mass parameter of the five dimensional fermion field)
- Can also scan in **RPV Slepton mass** vs. **coupling** plane