Dark Sector searches in CMS

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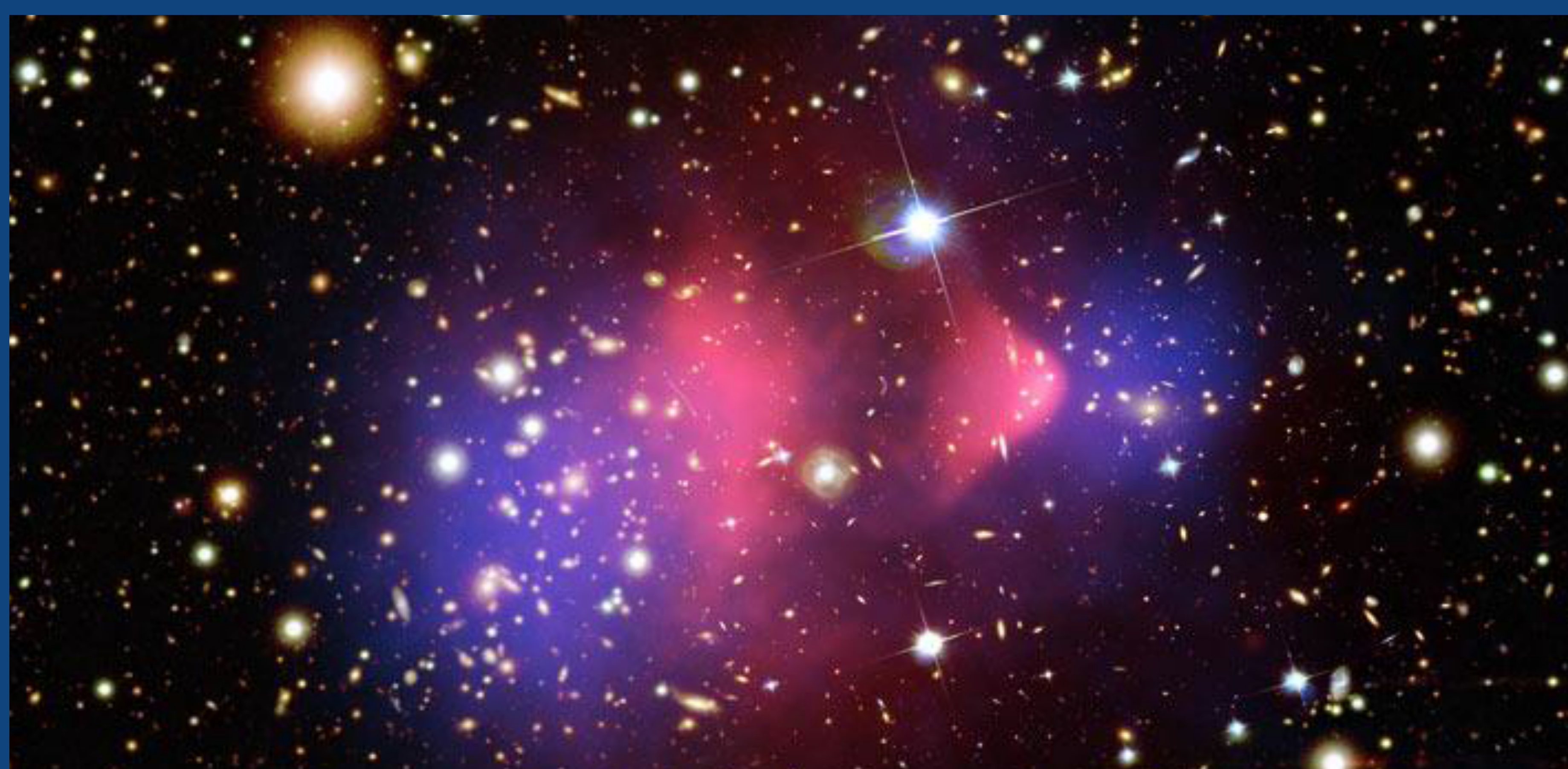
on behalf of the CMS Collaboration



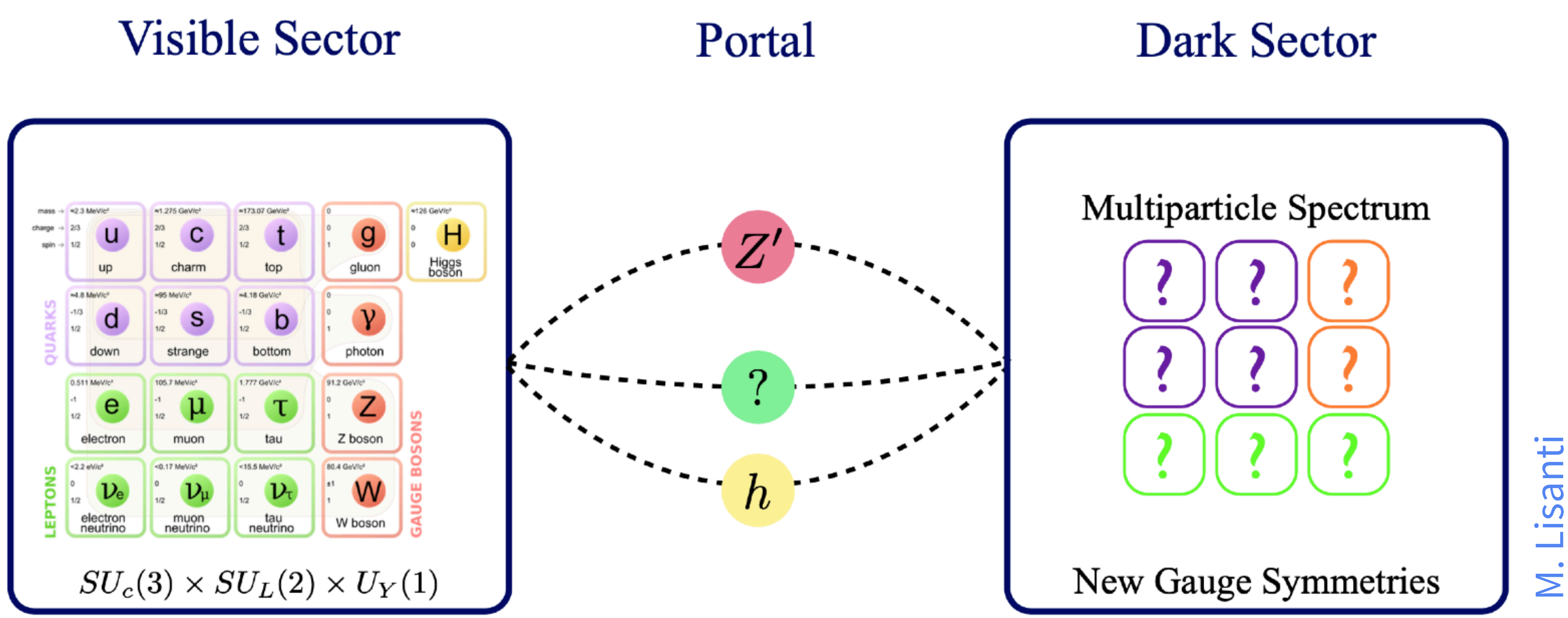
Dark Sectors: beyond *minimality*

DM might not be *minimal* !

Extended *dark sectors (DS)* of particle content predicted in a variety of BSM theories

- New hidden symmetries and particles accessible through portals
- Stable dark particles are good candidates for DM

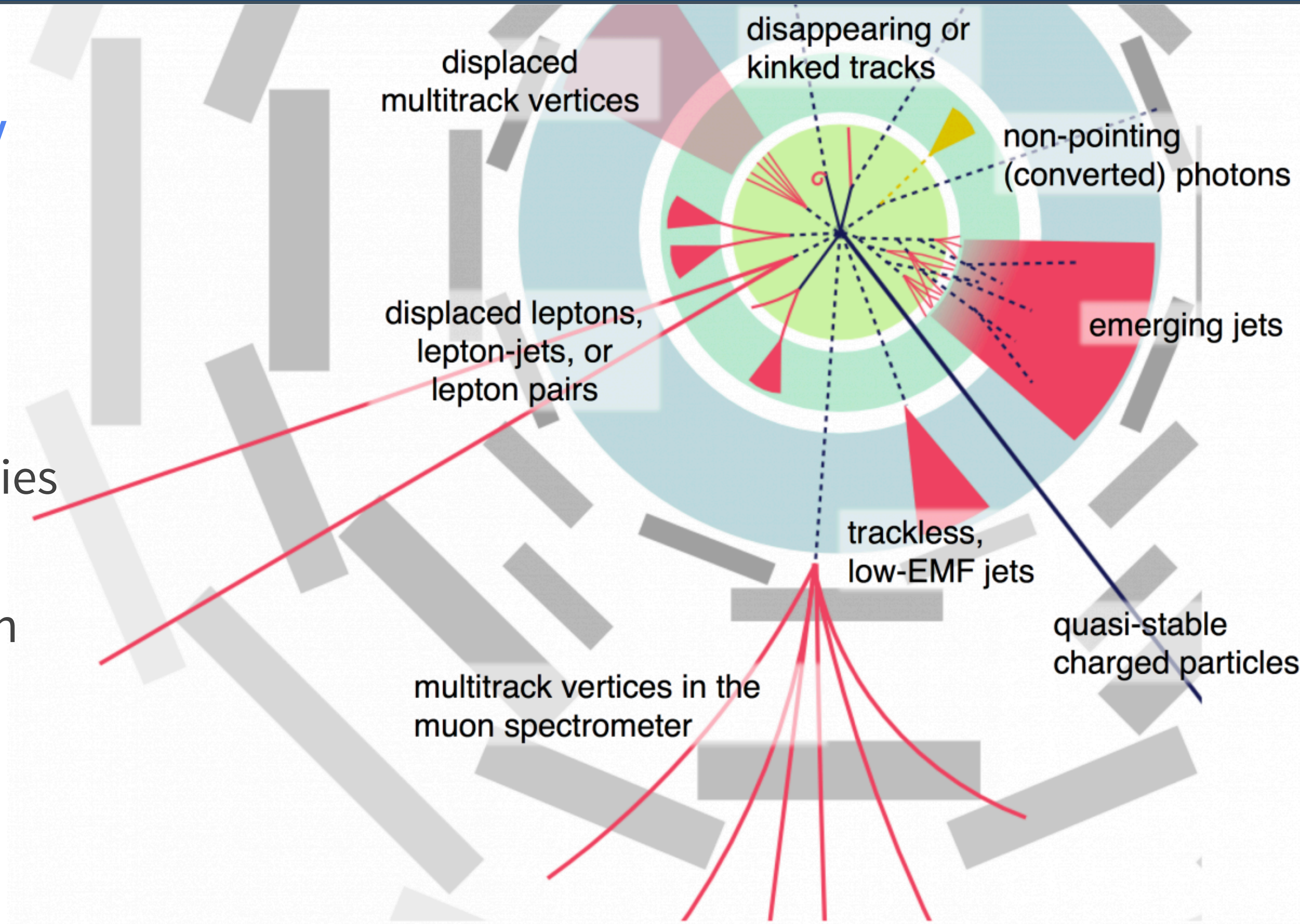
Dark sectors possibly accessible at the LHC



Novel experimental signatures

New and rich phenomenology

- Unconventional signatures
  - often rich of displaced vertices
- Requiring dedicated analysis strategies
  - including ad hoc trigger, reconstruction, and identification algorithms



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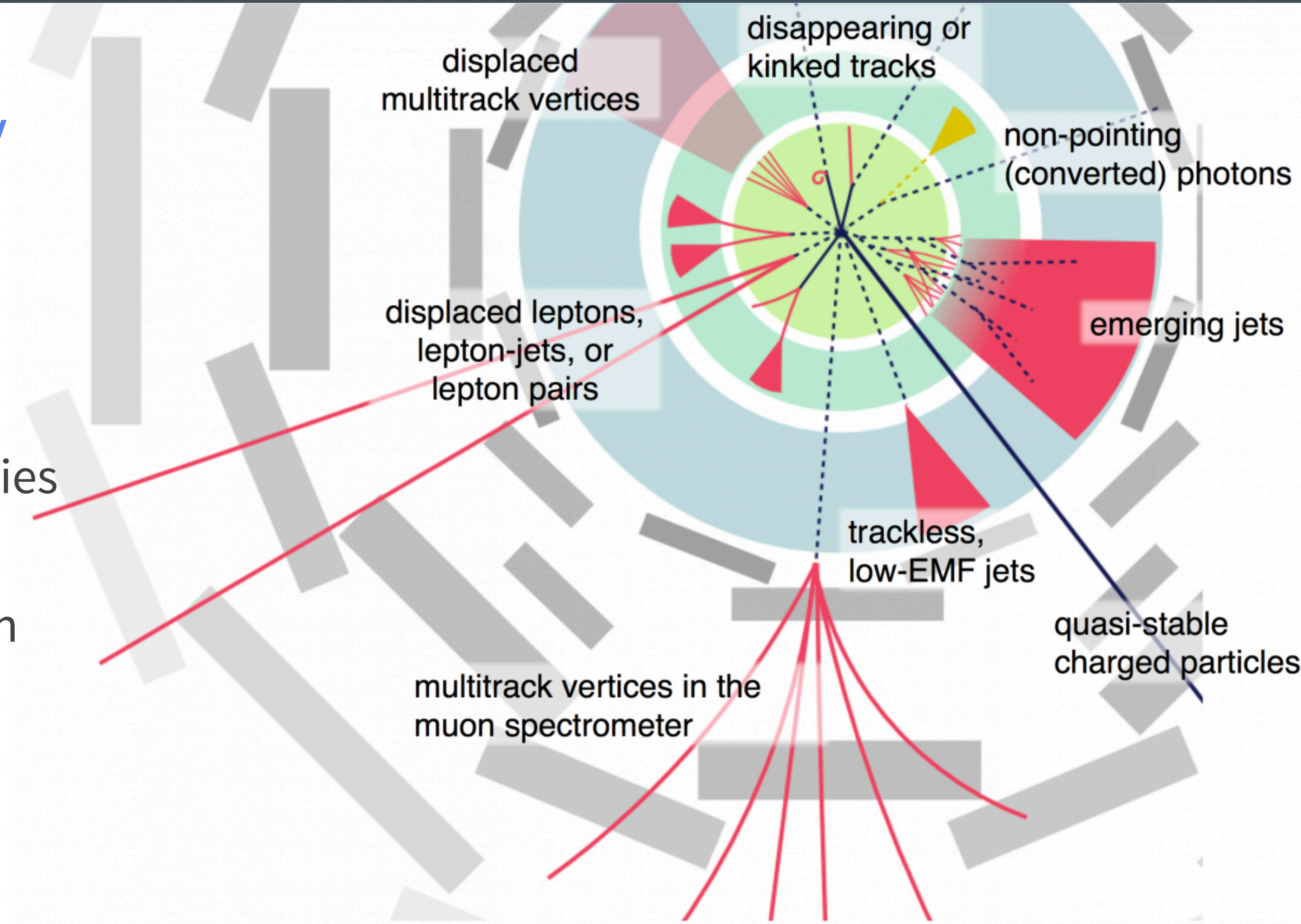
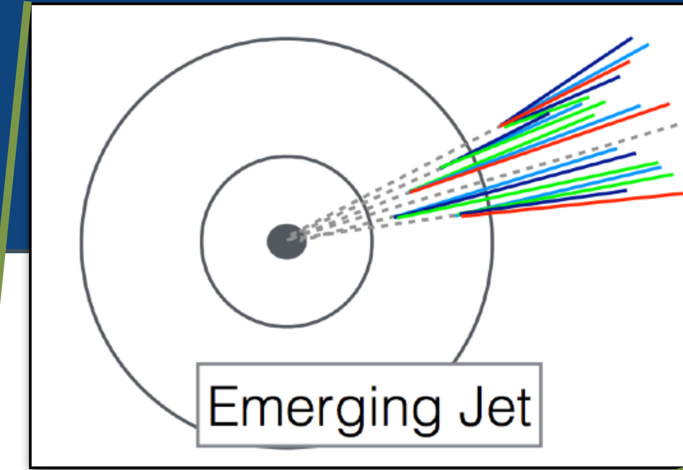


In this talk a selection of the latest CMS results from the quest for dark sector particles

A complete overview is available at:

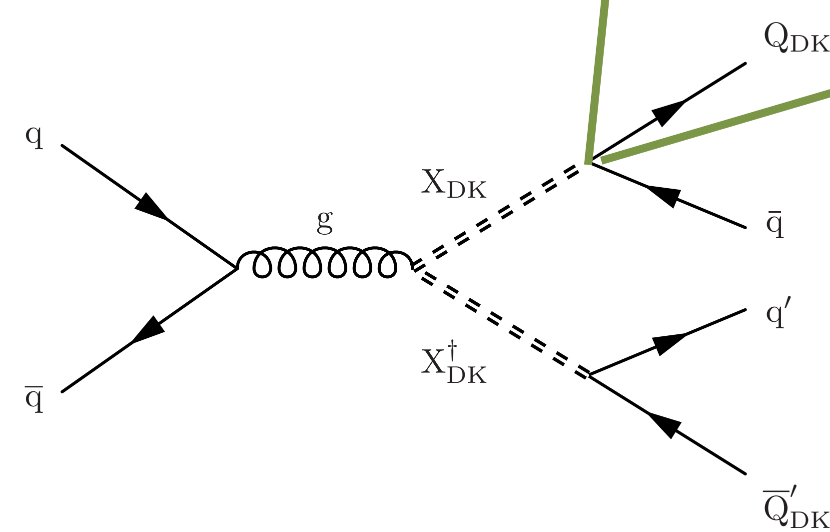
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO

Emerging jets

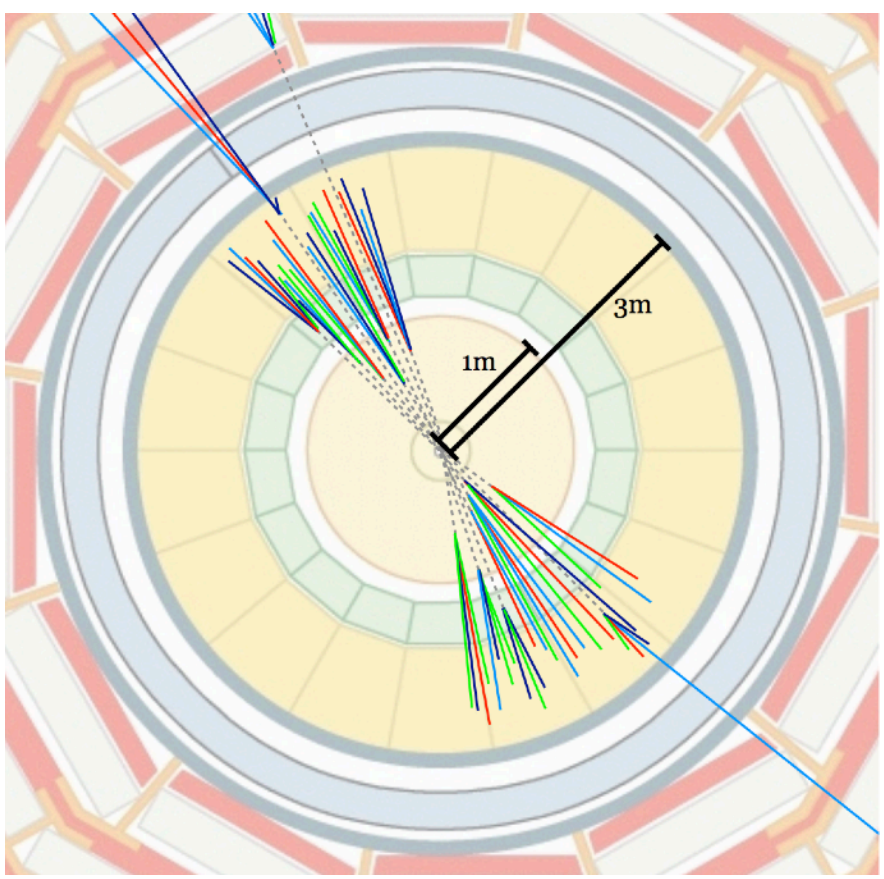


Electrically neutral dark quarks (Q_{DK})

- Self interacting within the dark sector
  - via a new QCD-like fundamental force
- SM-DS interaction mediated by a new particle charged under both SM and dark QCD



2 SM jets +
2 Emerging jets



- Dark shower signature →Emerging jet
  - multiple displaced vertices from dark pion decays

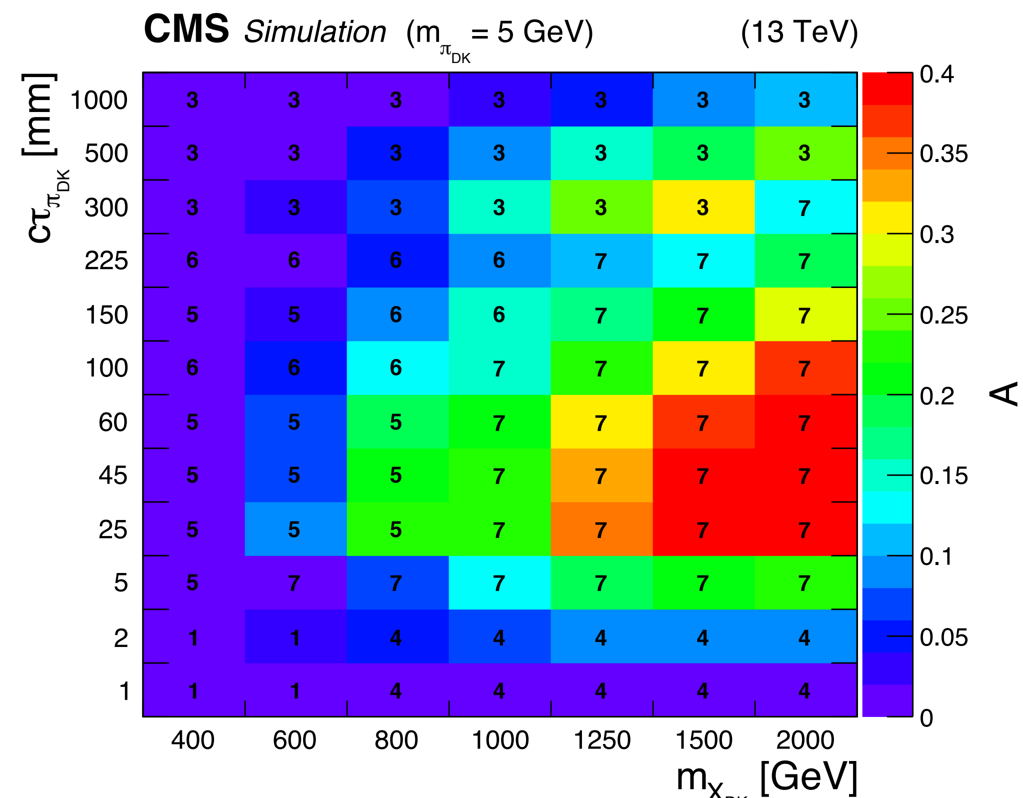
$$c\tau \approx 80\,\mathrm{mm}\left(\frac{1}{\kappa^4}\right)\left(\frac{2\,\mathrm{GeV}}{f_{\pi_{DK}}}\right)^2\left(\frac{100\,\mathrm{MeV}}{m_{\mathrm{down}}}\right)^2\left(\frac{2\,\mathrm{GeV}}{m_{\pi_{DK}}}\right)\left(\frac{m_{X_{DK}}}{1\,\mathrm{TeV}}\right)^4$$

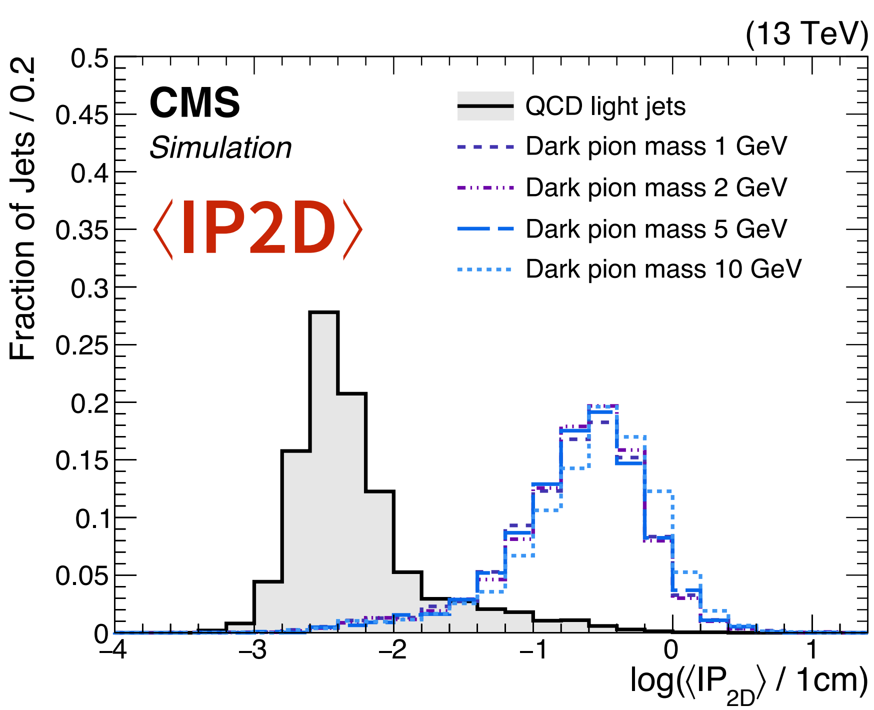
  - can have large p_T^{miss} if decay length ~ detector size

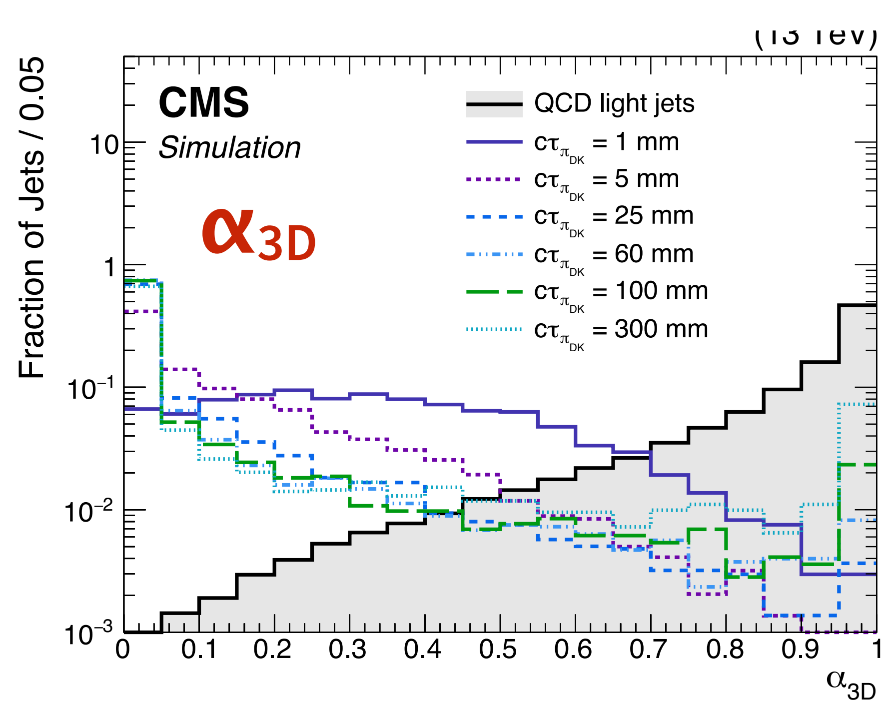
Emerging jets: data selection

EJ selection based on multiple displaced vertices identification

- **⟨IP_{2D}⟩**: Transverse impact parameter of associated tracks correlated to dark meson proper decay length
  - expected small ⟨IP_{2D}⟩ for SM jets
- **α_{3D}**: jet p_T fraction associated to prompt tracks
  - expected large α_{3D} for SM jets
- **7 sets of selection requirements,** addressing different models







Acceptance of selection criteria ranges from few % to 48% for massive mediators

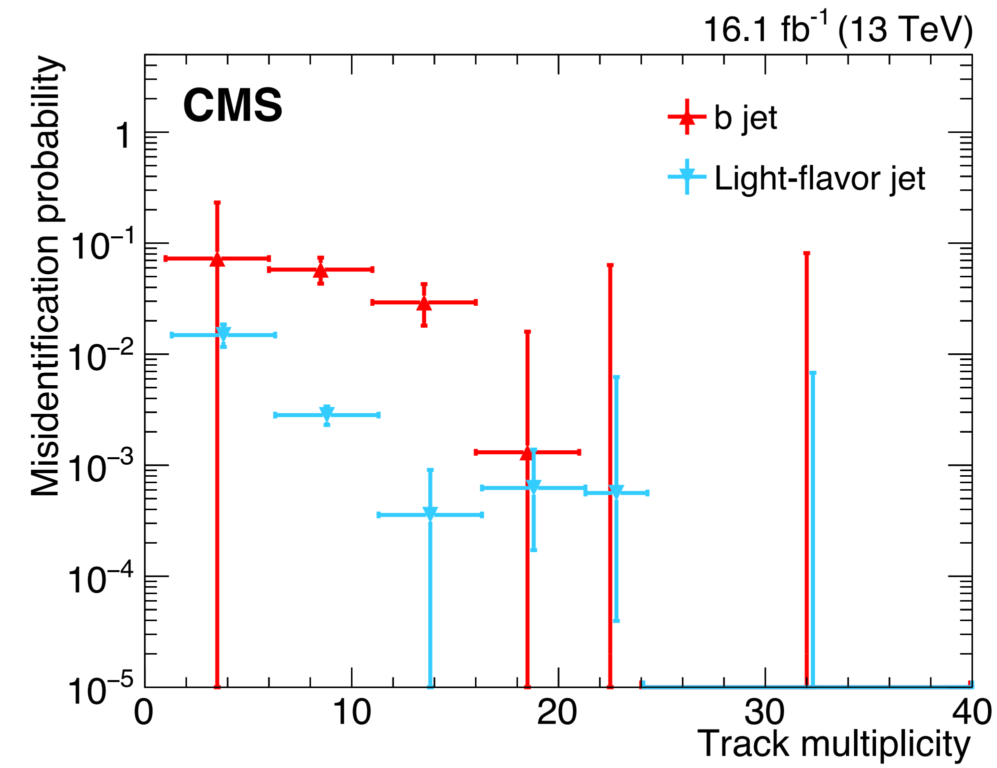
Emerging jets: backgrounds

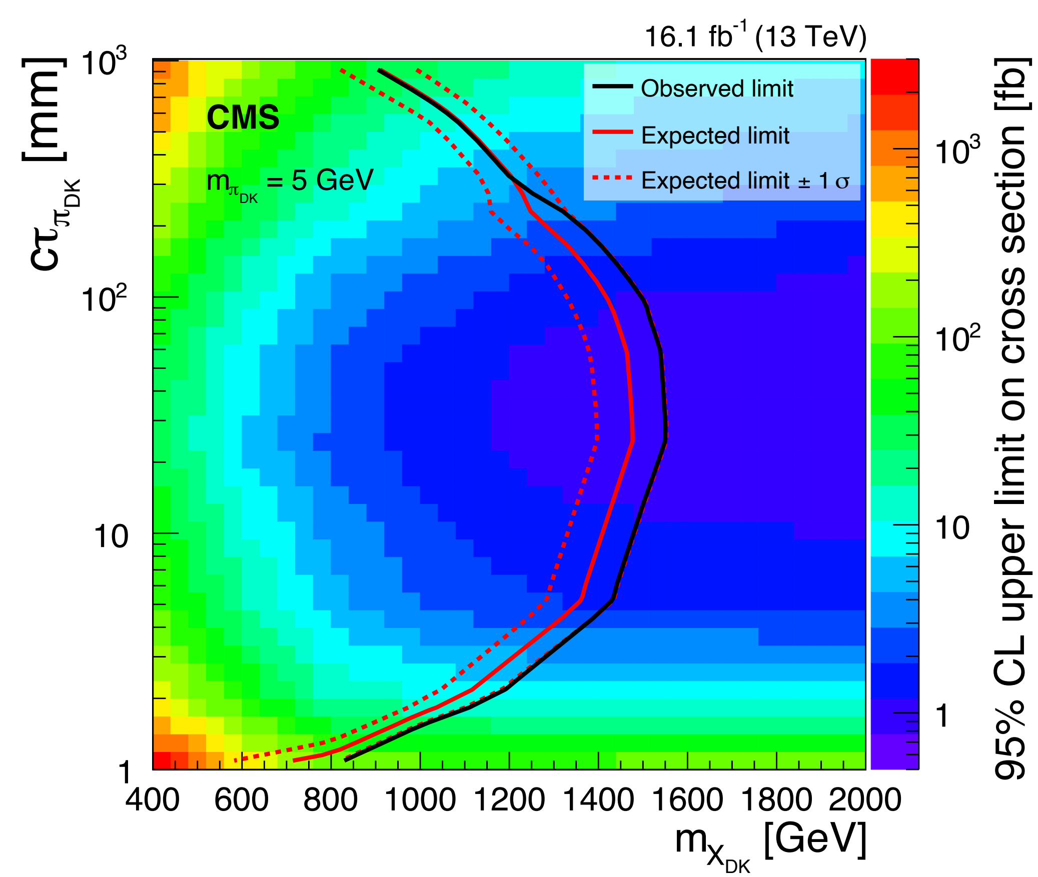
- Dominant background from multijet events
  - Long-lived B mesons content
  - Track mis-reconstruction
  - Artificial p_T^{miss} due to jet mis-reconstruction
- Mis-identification (Fake) rate measured in data in γ+jets CRs (enriched in light and b jets)

$$\text{Fake Rate} \equiv \epsilon_f(n_{\text{track}}) = \frac{N^{\text{pass}}_{jet}(n_{\text{track}})}{N^{\text{all}}_{jet}(n_{\text{track}})}$$

No significant excess observed over SM background expectation

DM mediators with mass between 400 and 1250 GeV and dark pion decay lengths between 5 and 225 mm excluded



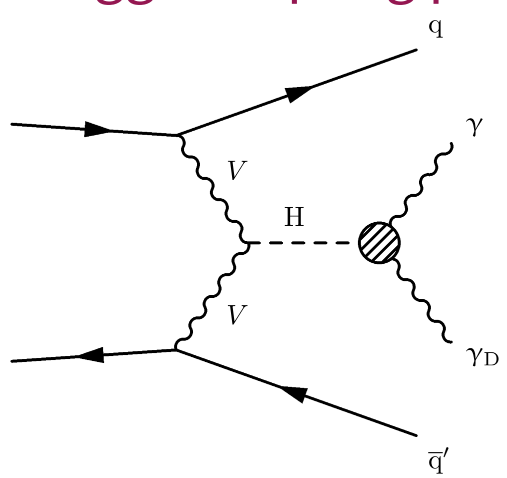


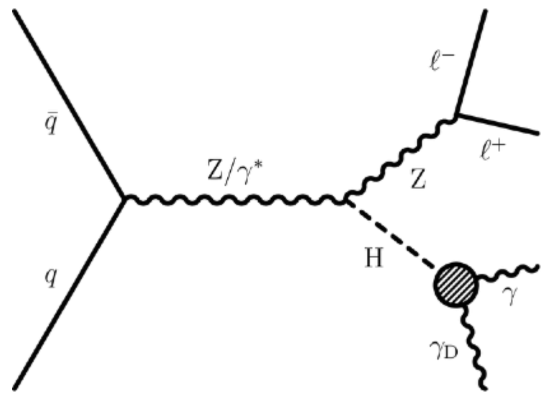
Dark photon from Higgs decay

Some models predict a scalar Higgs boson coupling to a dark photon through a dark sector

- New unbroken U(1) symmetry
- Might be a heavier Higgs boson

Dark photon-Higgs coupling probed in Higgs boson production (VBF or Z associated prod.)





Associated Z production

- 2 opposite charged same flavour high p_T leptons compatible with Z boson decay recoiling against $p_T^{miss} + \gamma$
- Use transverse mass as a discriminating variable
- ~139 fb^{-1} of data analysed (2016 - 2018)

VBF production

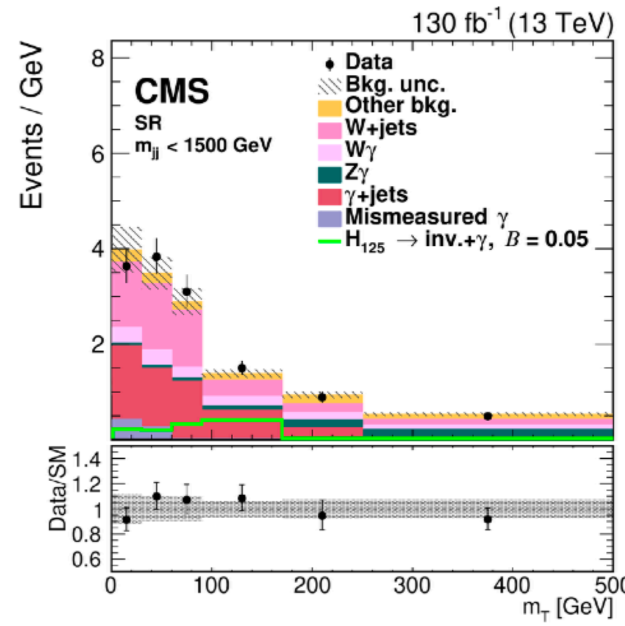
- 2 large $|\Delta\eta|$, light jets recoiling against $p_T^{miss} + \gamma$
- Use transverse mass as a discriminating variable
- ~130 fb^{-1} of data analysed (2016 - 2018)

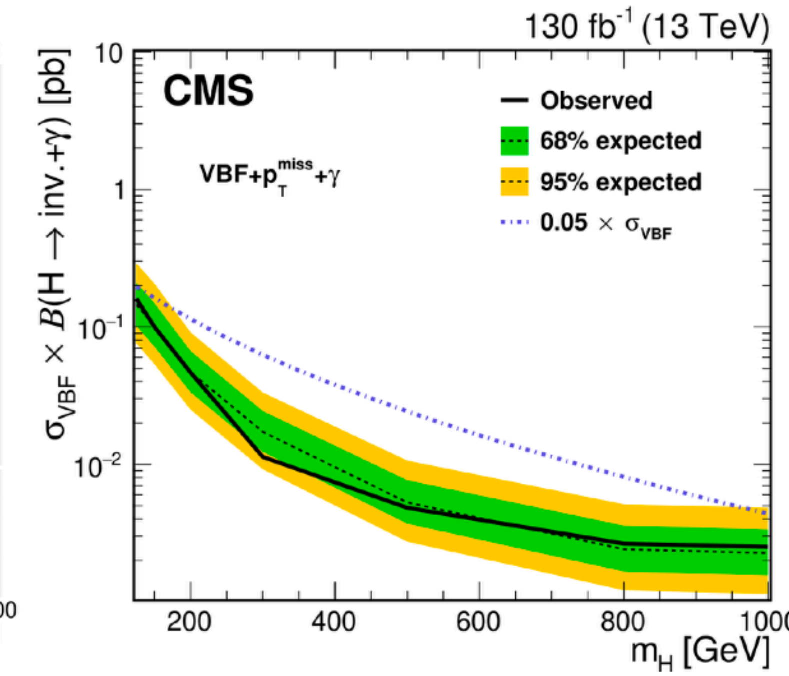
Dark photon from Higgs decay

VBF production

Background yields estimated from CRs

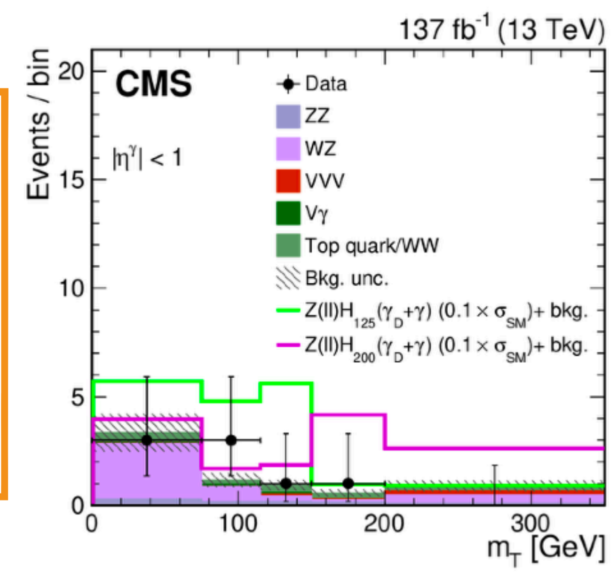
- Dominant background from W(eν)+ jets (e misidetified as γ)
- W(ℓν)+γ dominates at large p_T^{miss}
- γ+jets with mismeasured jets or γ

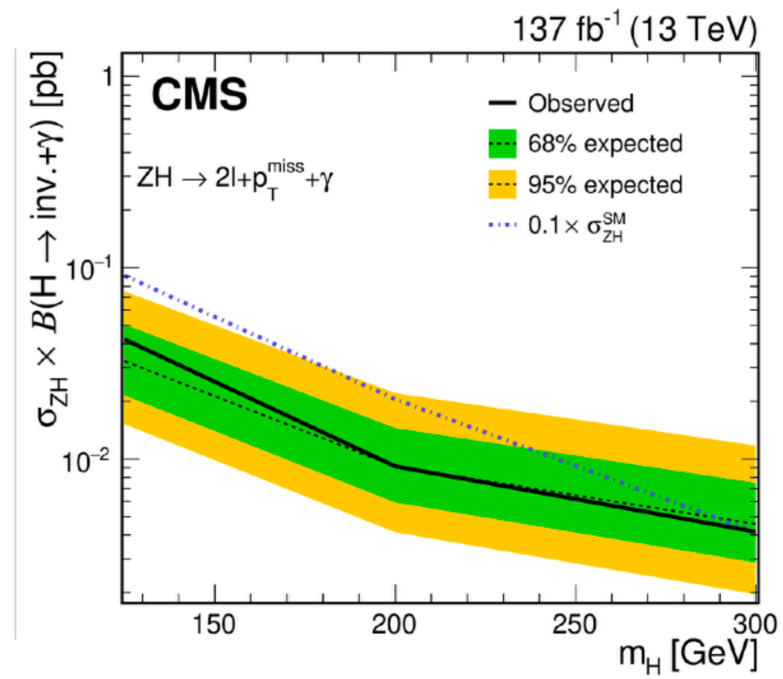




Associated Z production

- Dominant background from in W(eν)Z($\ell\ell$) with genuine p_T^{miss} and e misidetified as γ
- Non resonant bkg from WW and top processes estimated from CR enriched in eμ events





Observed and expected 95% CL limits on BR(H→γγ$_D$) for m_H=125 GeV

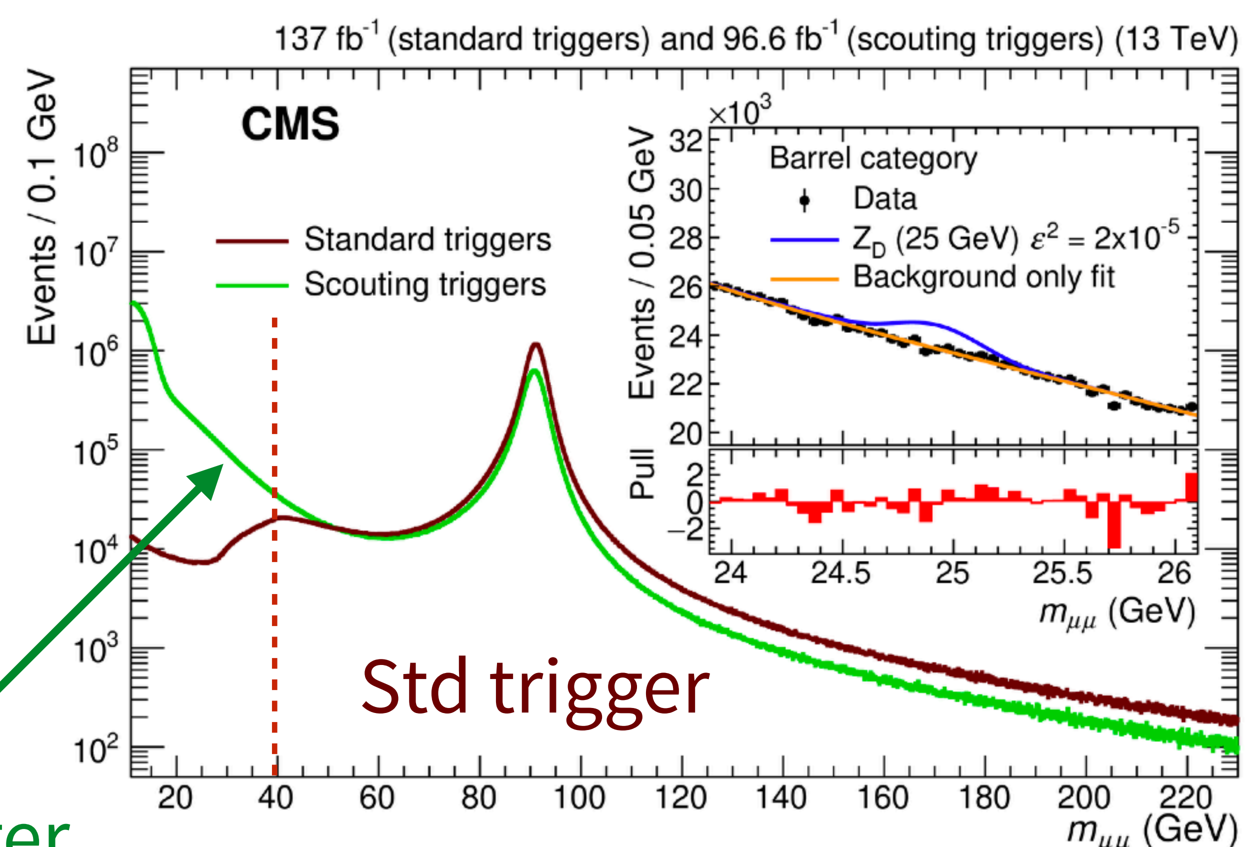
VBF		ZH		VBF+ZH	
Obs. (%)	Exp. (%)	Obs. (%)	Exp. (%)	Obs. (%)	Exp. (%)
3.4	$2.7^{+1.2}_{-0.8}$	4.6	$3.6^{+2.0}_{-1.2}$	2.9	$2.1^{+0.9}_{-0.6}$

Dark photon decaying into a pair of muons

Search for narrow resonance decaying to a pair of opposite charged muons in the mass range 11.5-200 GeV (omitting Z mass window)

- Search extended to low $m_{\mu\mu}$ values (<40 GeV) using data with reduced trigger level information: *scouting triggers*
- Events divided in 2 cat. based on the number of muons reconstructed in the central region
  - to account for different resolution of central and forward muons

Simultaneous binned maximum likelihood fit performed to $m_{\mu\mu}$ in the 2 categories

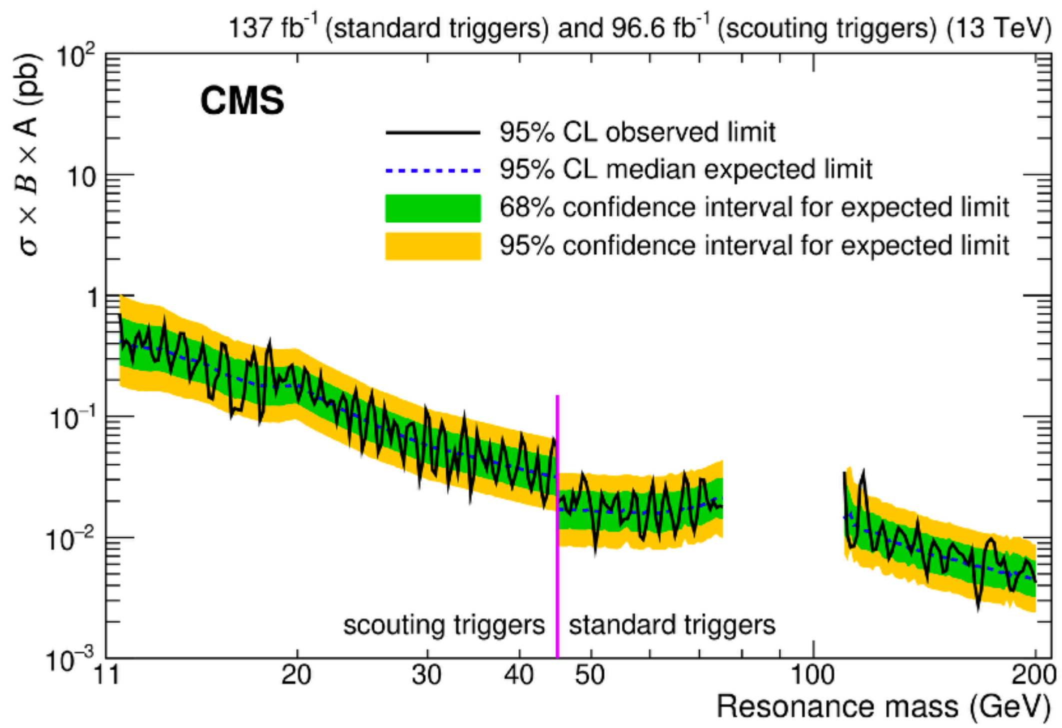


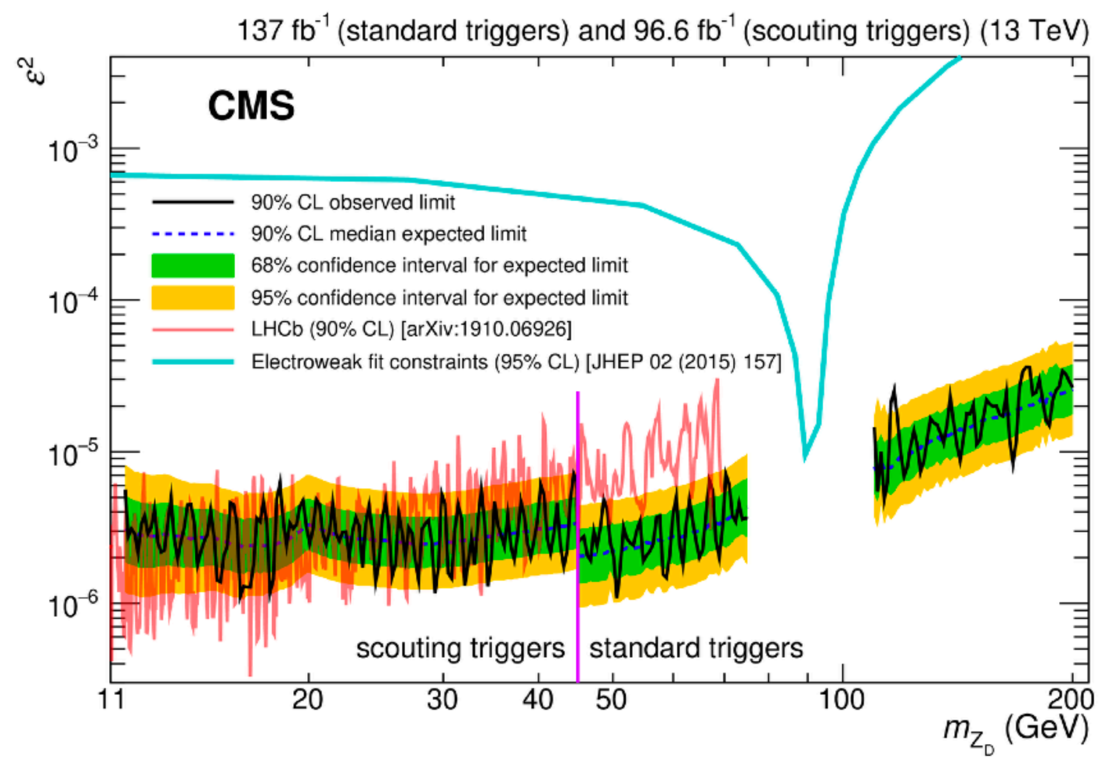
Scouting trigger

Dark photon decaying into a pair of muons

- Results interpreted in the context of a dark photon model: dark photon feebly couples SM particles to a hidden, dark sector
  - Mixing of $U(1)_D$ gauge field with SM $U(1)_Y$ ypercharge field
    - degree of mixing (and strength of the coupling) determined by the kinetic mixing coefficient **ε**

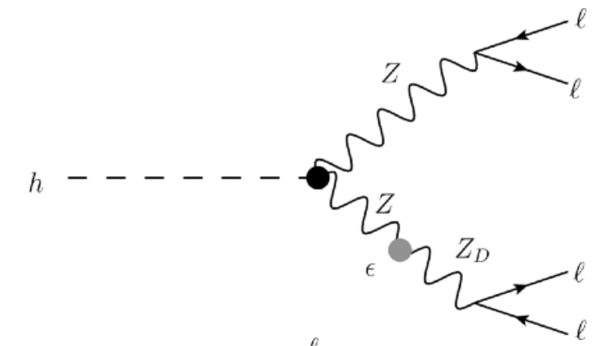
Strong constraint on the kinetic mixing coefficient of a dark photon with mass > 11.5 GeV

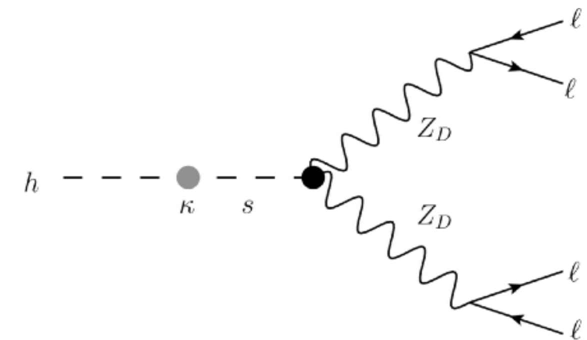




Higgs decaying to dark photons

- In the context of a dark $U(1)_D$ gauge symmetry we might have
  - Higgs decaying to a pair of dark photons (Z_D)
    - via Kinetic mixing coupling proportional to $\boldsymbol{\varepsilon}$
    - via Higgs mixing (k)
  - Proper dark photon lifetime $c\tau_0$ inversely proportional to ε^2



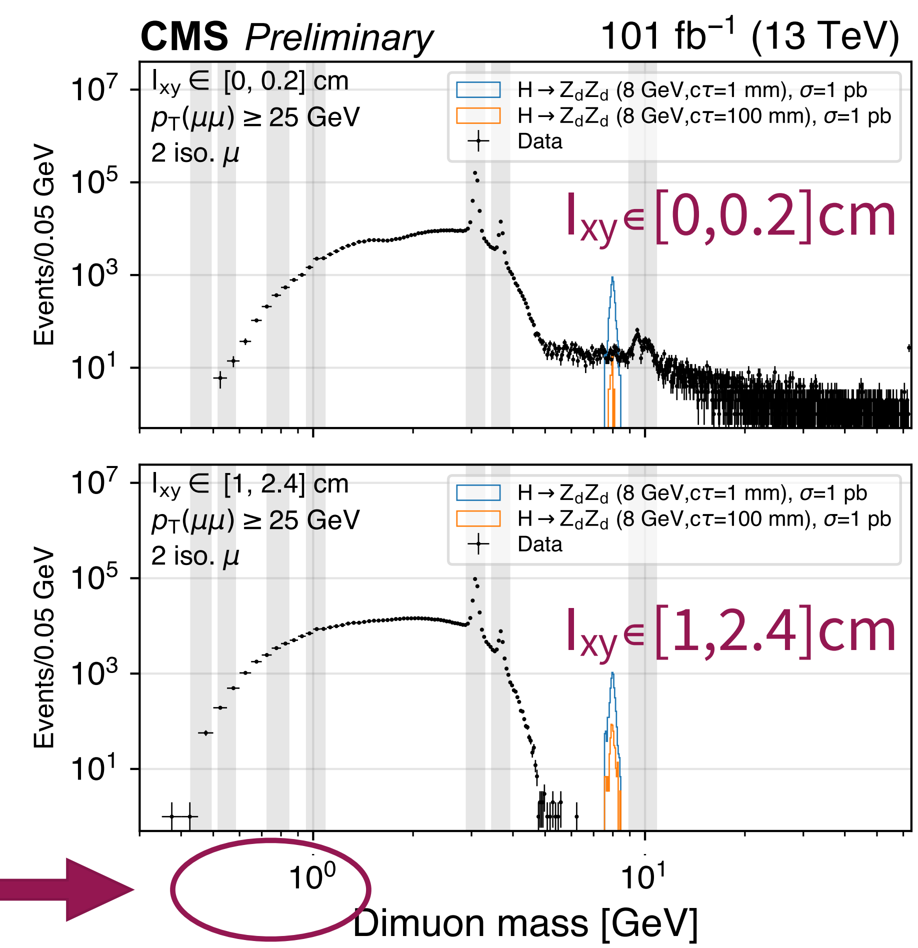


Events with at least 2 displaced muons associated to displaced vertex (DV)

Non-zero displacement (lay up to 11 cm)

CMS Pixel tracker geometry used to categorise events based on the displacement (l_{xy})

maximising the sensitivity to different signal topologies

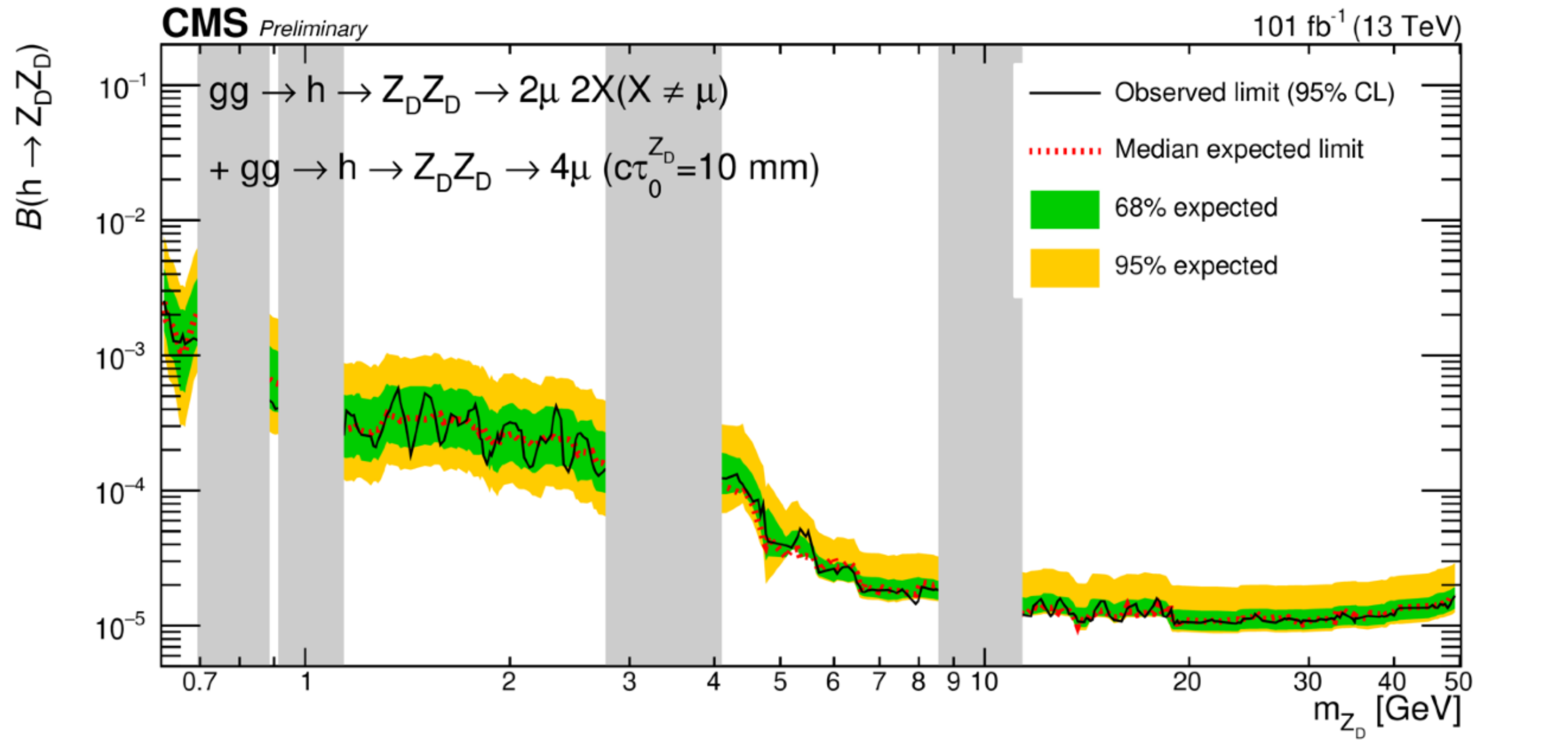


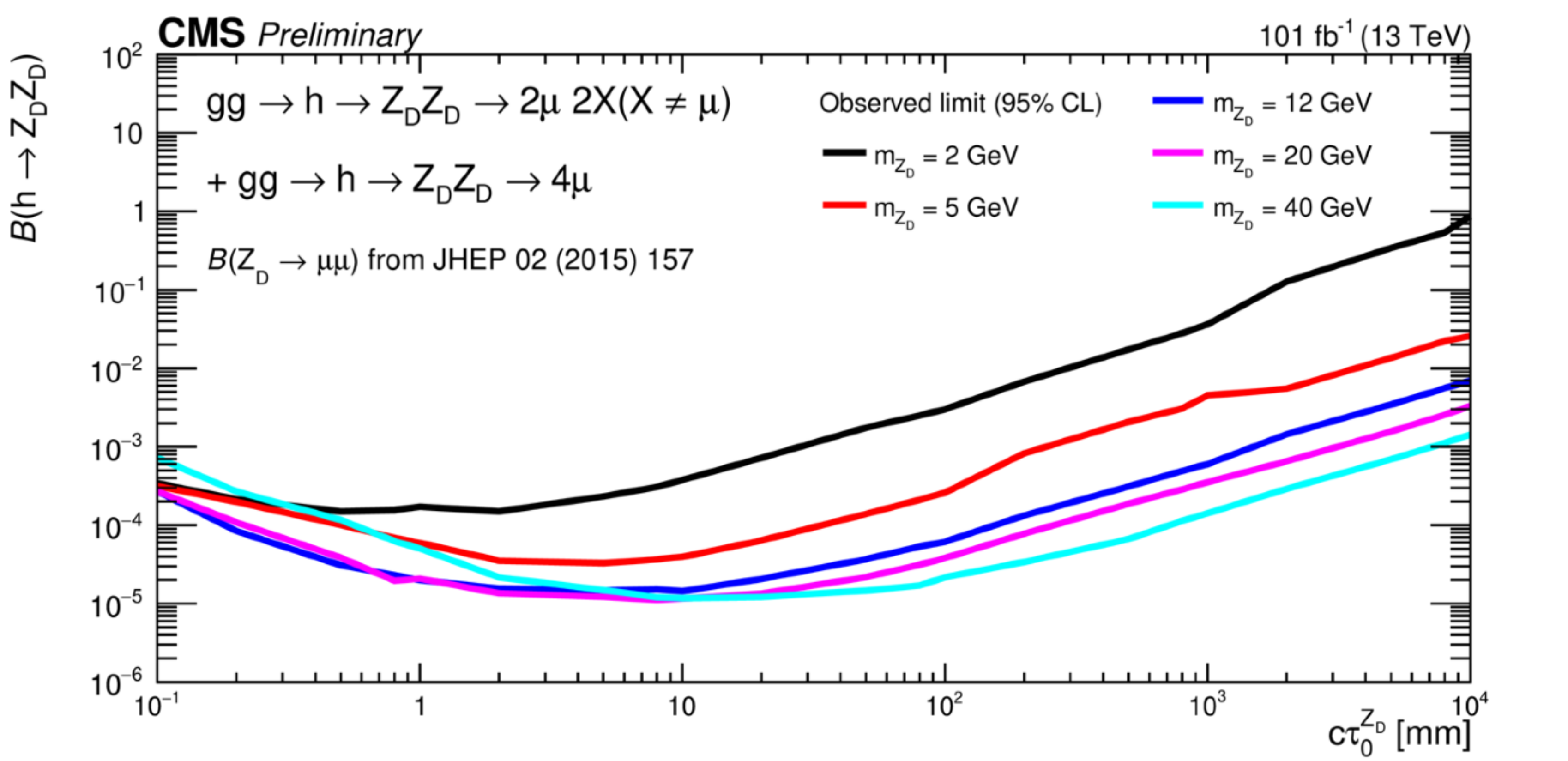
Scouting data enable reaching low masses

101 fb^{-1} of data from 2017 and 2018 data taking

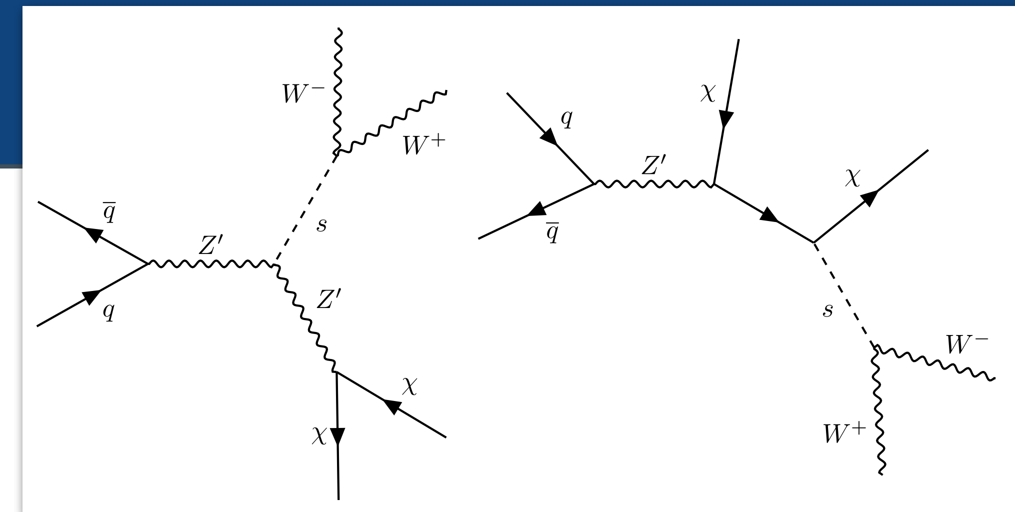
Higgs decaying to dark photons

- Categorization in bins of l_{xy}, $p_T^{\mu\mu}$ and isolation
  - Search for resonant dimuon peak in each mass window
- Fit to dimuon mass distribution
  - know resonances mass ranges are excluded from the search





Dark Higgs



Dark Higgs model: DM particles acquire mass through their interaction with a dark Higgs boson s

- WW decay mode dominates for s>160 GeV

Dilepton channel: 3D ML fit to ΔR(ll) - m_{ll} - $m_T(l_{min} + p^T_{miss})$

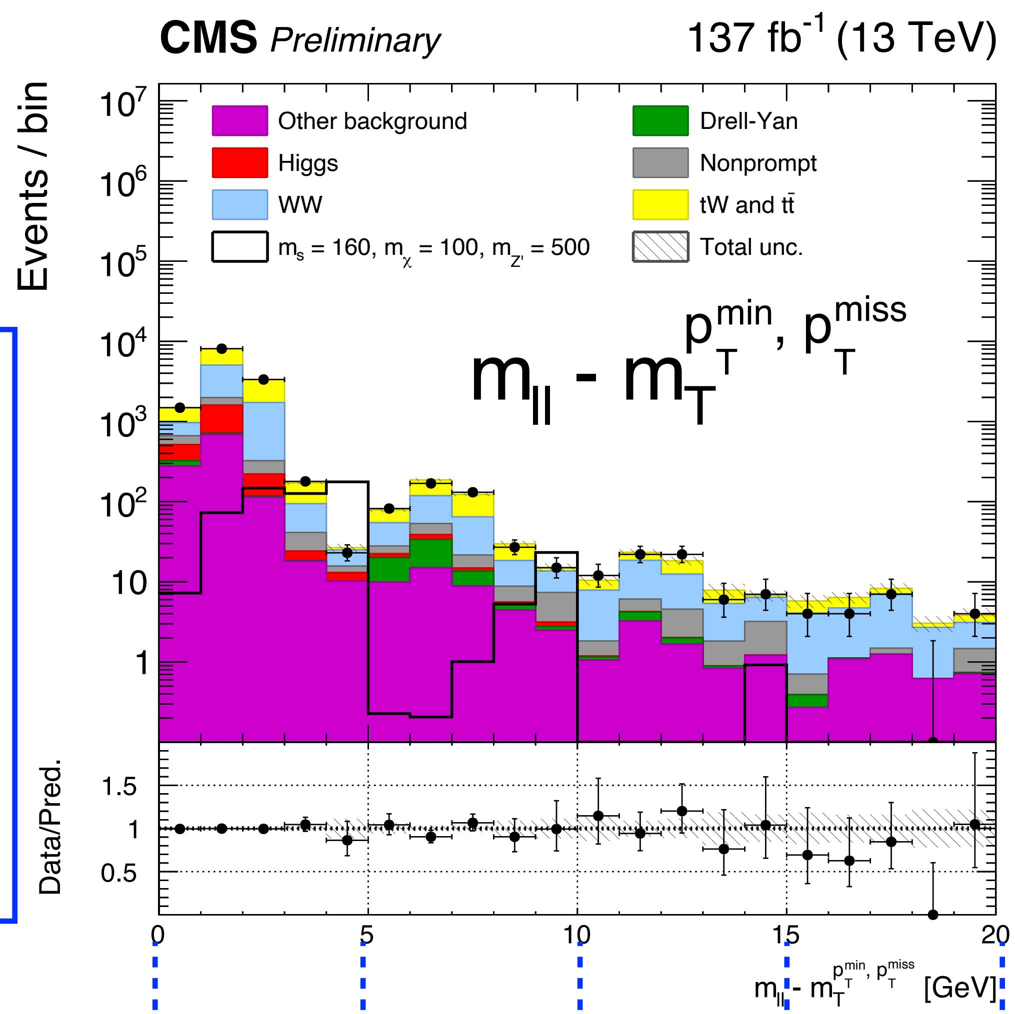
3 SR in ΔR(ll)

Most stringent limit for m_χ = 150 GeV

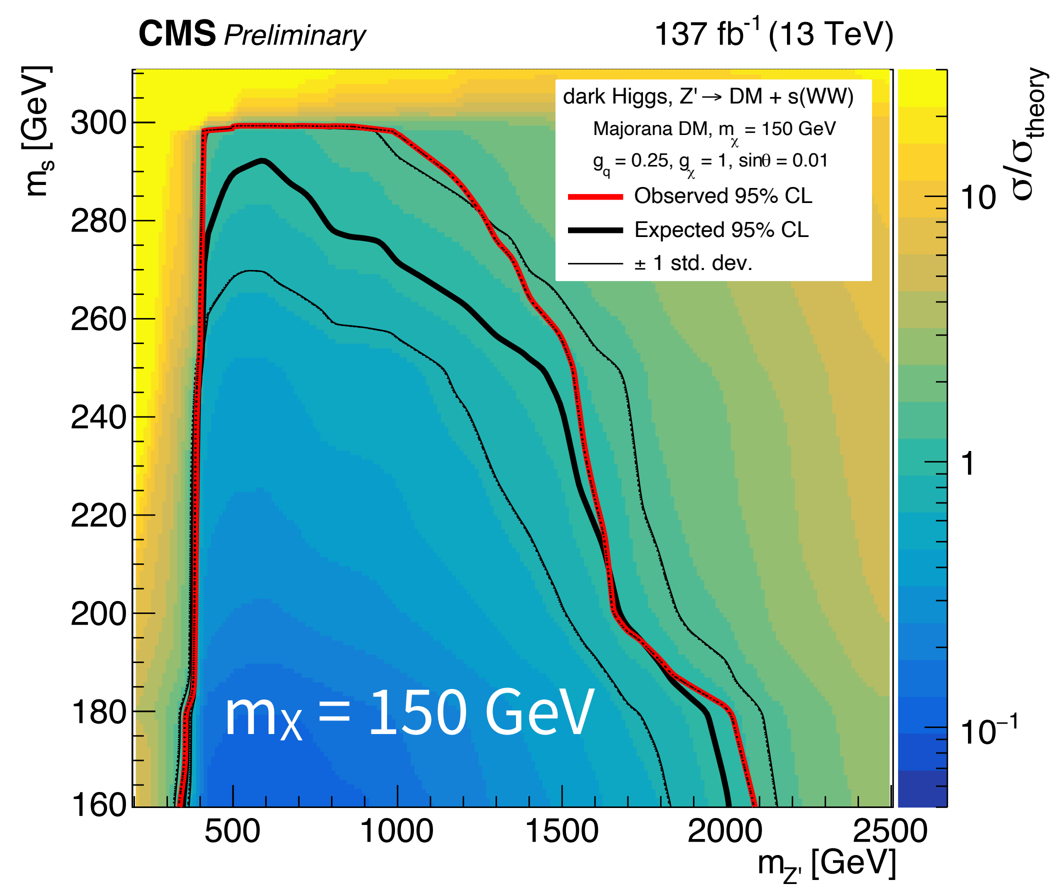
m_s up to ~300 GeV in ~480<$m_{Z'}$<~1200 GeV

$m_{Z'}$ up to ~2000 GeV for m_s = 160 GeV

SR1: 0.0 < ΔR(ll)< 1.0



12<mℓℓ<60 | 60<mℓℓ<90 | 90<mℓℓ<120 | 120<mℓℓ<Inf



Conclusions

- New Physics might be hiding in a dark sector
  - DS physics expected to manifest through a a variety of atypical signatures at colliders
  - New ground for discovery opportunities
- Unique challenges in trigger, reconstruction, background estimation
  - Dedicated analysis strategies are being conceived to enable exploration of this uncharted territory

Dark sector searches are just at a start: Stay tuned!

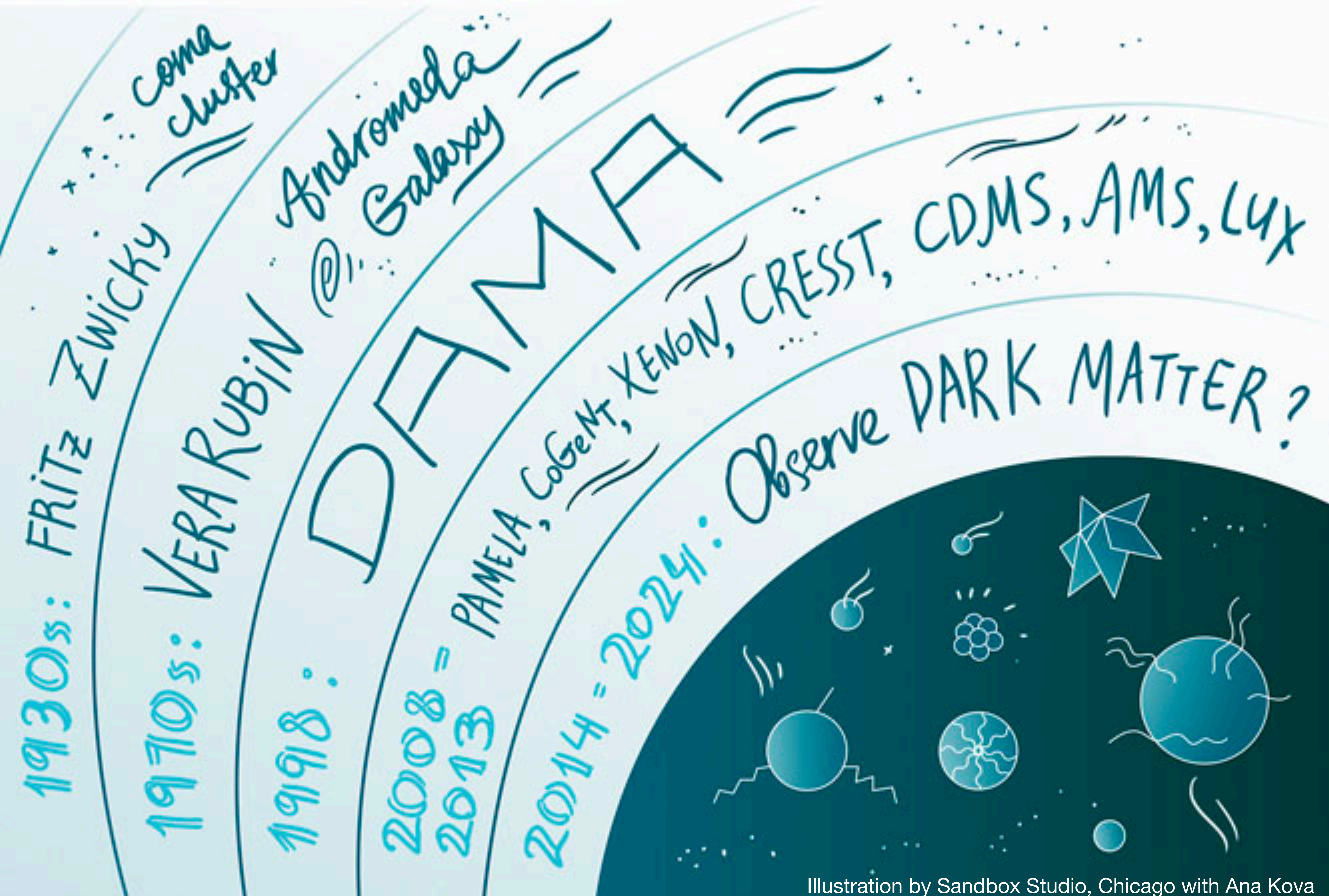


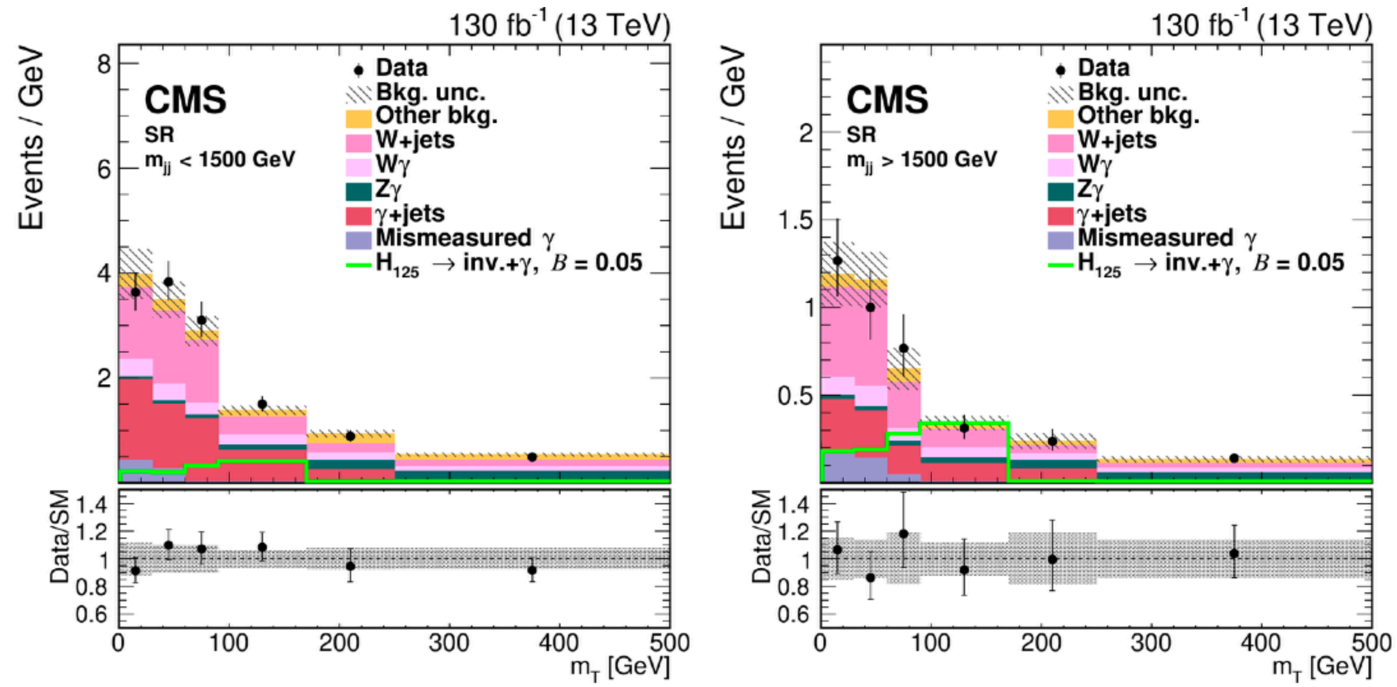
Illustration by Sandbox Studio, Chicago with Ana Kova

Additional Material

Dark photon from Higgs decay

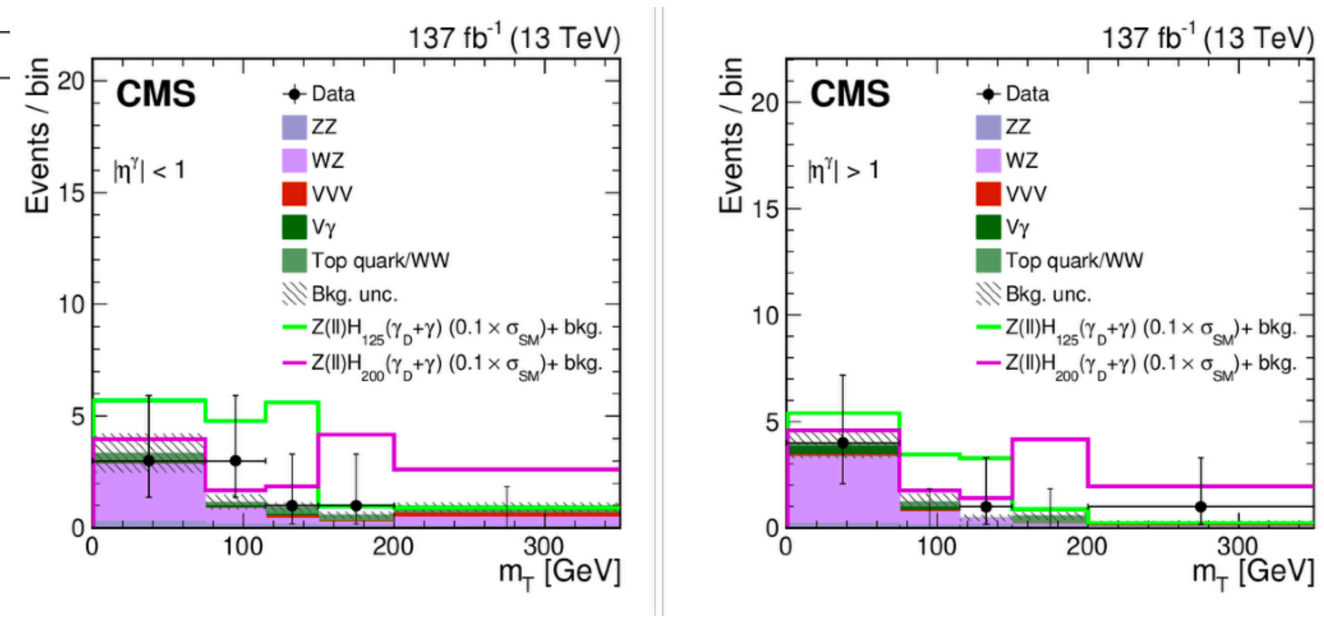
VBF Higgs production

Data-taking year	2016	2017/2018	
Trigger	VBF+γ	Single-photon	$p_{\mathrm{T}}^{\mathrm{miss}}$
Number of photons		$\geq$1 photon	
p_{T}^{γ}	$>$80 GeV	$>$230 GeV	$>$80 GeV
Number of leptons		0	
$p_{\mathrm{T}}^{\mathrm{j}_1} / p_{\mathrm{T}}^{\mathrm{j}_2}$		$>$50 GeV	
$p_{\mathrm{T}}^{\mathrm{miss}}$	$>$100 GeV	$>$140 GeV	$>$140 GeV
Jet counting		2–5	
m_{jj}		$>$500 GeV	
$\lvert\Delta\eta_{\mathrm{jj}}\rvert$		$>$3.0	
$\eta_{\mathrm{j}_1}\eta_{\mathrm{j}_2}$		$<$0	
$\Delta\phi_{\mathrm{jet},\vec{p}_{\mathrm{T}}^{\mathrm{miss}}}$		$>$1.0 radians	
z_{γ}^{*}		$<$0.6	
$p_{\mathrm{T}}^{\mathrm{tot}}$		$<$150 GeV	



Associated Higgs production

Variable	Selection	Reject
Number of leptons	Exactly 2 leptons, $p_{\mathrm{T}} > 25/20$ GeV	WZ, ZZ, VVV
Number of photons	$\geq$1 photon, $p_{\mathrm{T}}^{\gamma} > 25$ GeV	All but Zγ
$\lvert m_{\ell\ell} - m_{\mathrm{Z}}\rvert$	$<$15 GeV	WW, Top quark
$p_{\mathrm{T}}^{\mathrm{miss}}$	$>$110 GeV	Zγ
$p_{\mathrm{T}}^{\ell\ell}$	$>$60 GeV	Zγ
b jet veto	Applied	Top quark, VVV
Jet counting	$\leq$2	Top quark, VVV
$\Delta\phi_{\vec{\ell\ell},\vec{p}_{\mathrm{T}}^{\mathrm{miss}}+\vec{p}_{\mathrm{T}}^{\gamma}}$	$>$2.5 rad	Zγ
$\lvert p_{\mathrm{T}}^{\vec{p}_{\mathrm{T}}^{\mathrm{miss}}+\vec{p}_{\mathrm{T}}^{\gamma}} - p_{\mathrm{T}}^{\ell\ell}\rvert / p_{\mathrm{T}}^{\ell\ell}$	$<$0.4	Zγ
$\Delta\phi_{\mathrm{jet},\vec{p}_{\mathrm{T}}^{\mathrm{miss}}}$	$>$0.5 rad	Zγ
$m_{\ell\ell\gamma}$	$>$100 GeV	Zγ
m_{T}	$<$350 GeV	WW, Top quark



Dark Higgs

CMS-PAS-EXO-20-013

3 SR in ΔR(ll)