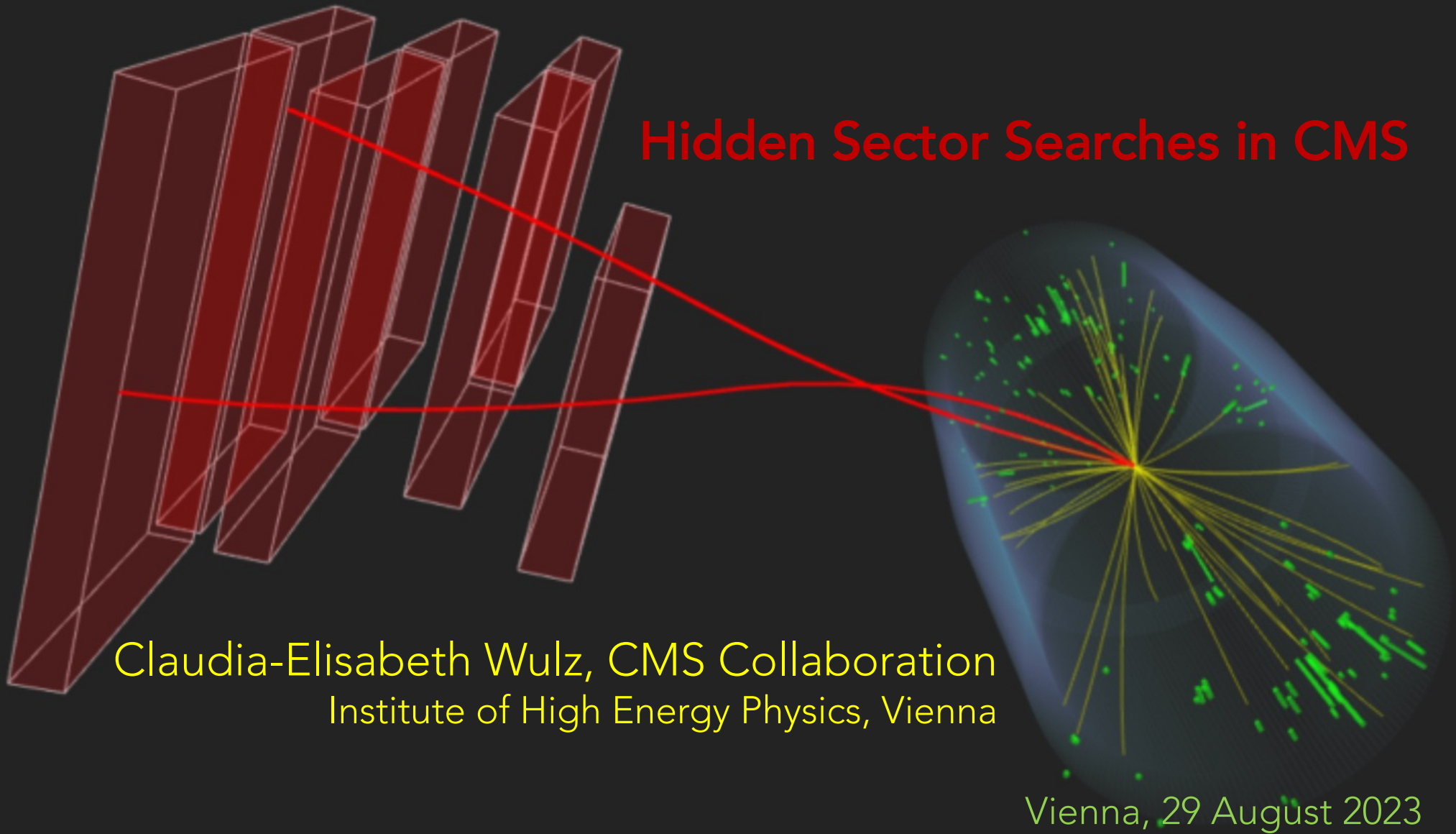
Hidden Sector Searches in CMS



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Motivation for a hidden sector

Incomplete Standard Model (SM)

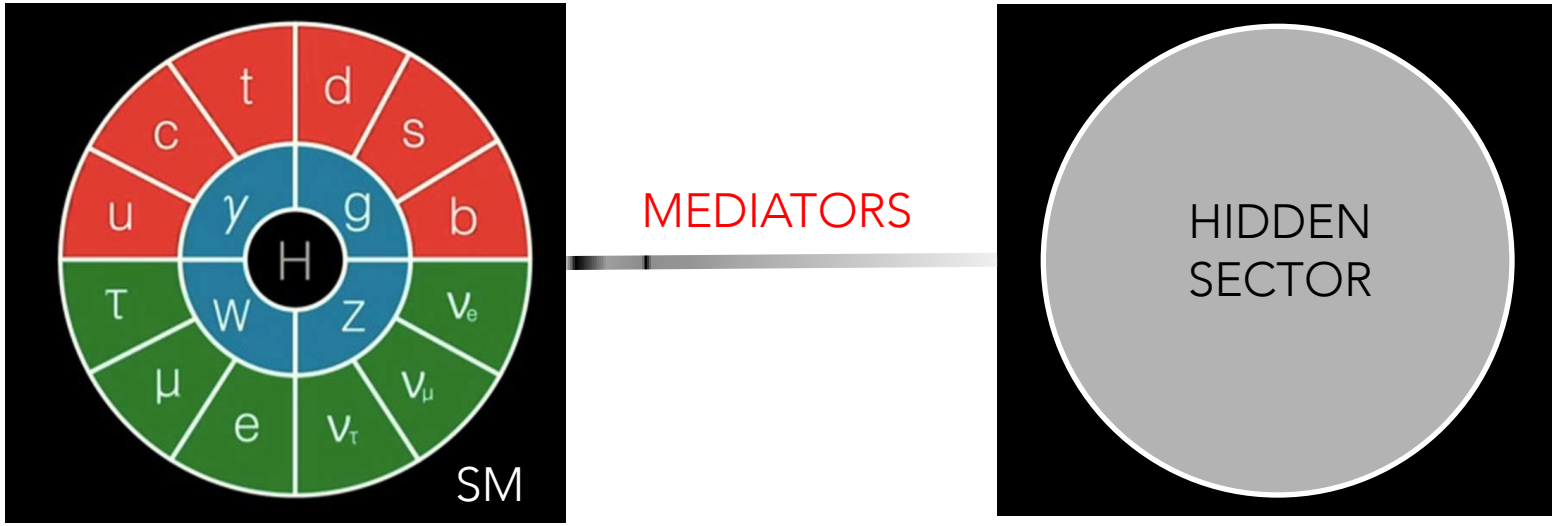
- Does not include dark matter, in particular

Experimental results so far

- No low-hanging fruits detected (e.g. WIMPS), in particular at the LHC

Hidden sector

- Rich ground to detect new phenomena
- Could interact with SM sector through mediators (portal interactions)
- Couplings of hidden sector particles to SM particles could be feeble, or strong
- Low-mass hidden sector particles recently of particular interest



CMS analyses presented in this talk

Low-mass dimuon resonances – dark photons

Search for prompt production of a GeV scale resonance decaying to a pair of muons in proton-proton collisions at $\sqrt{s}$ = 13 TeV

- EXO-21-005

Semivisible jets – dark QCD:

Search for resonant production of strongly coupled dark matter in proton-proton collisions at 13 TeV

- EXO-19-020, JHEP 06 (2022) 156

Dark Higgs (WW) + missing transverse momentum

NEW

Search for dark matter particles produced in W^+W^- events with transverse momentum imbalance in proton-proton collisions at $\sqrt{s}$= 13 TeV with the CMS detector

- EXO-21-012

All analysed data (up to 138 fb^{-1}) are from LHC Run 2 (2016-2018)

All CMS exotica results:
https://cms-results.web.cern.ch/cms-results/public-results/publications/EXO/index.html

CMS trigger

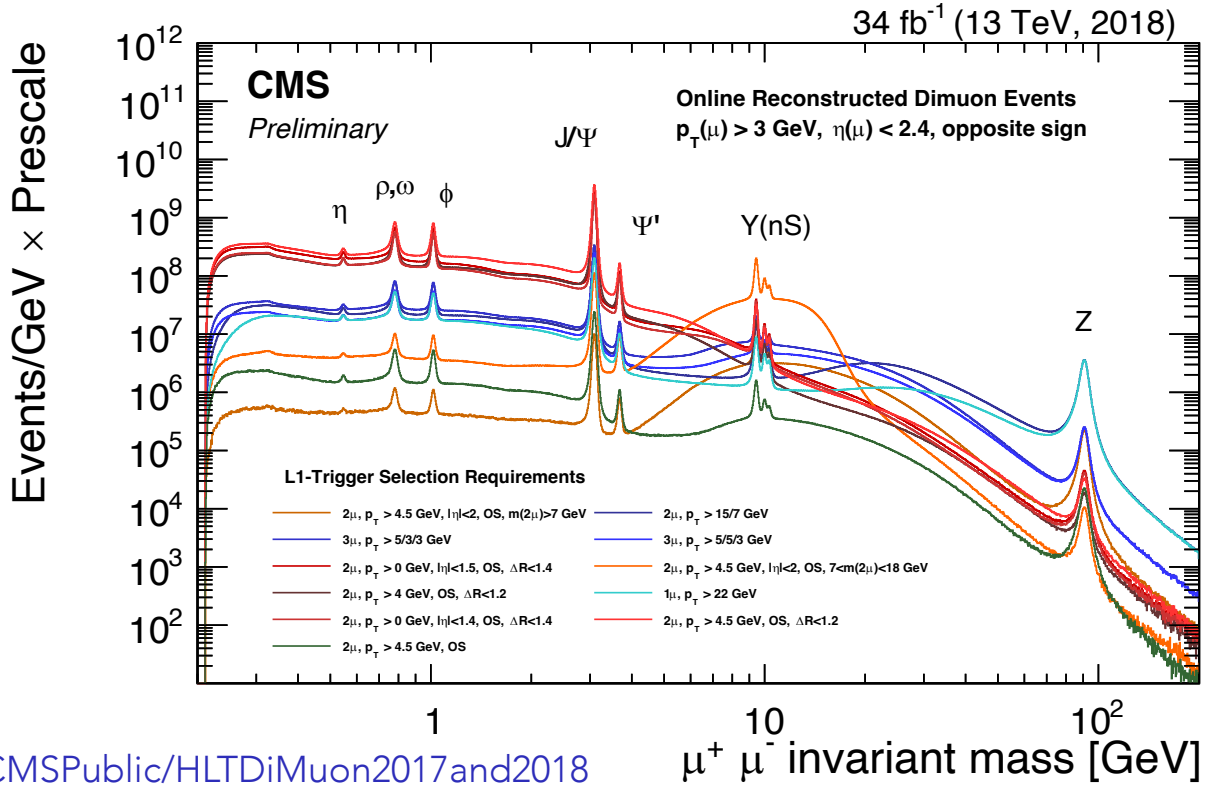
Two trigger levels

- Level-1 (L1): mostly programmable hardware, no tracker, standard rate 100 kHz
- High-level trigger (HLT): software, all detectors, standard rate 1 kHz
- Standard event size: 1 MB -> bandwidth 1 GB/s

Scouting

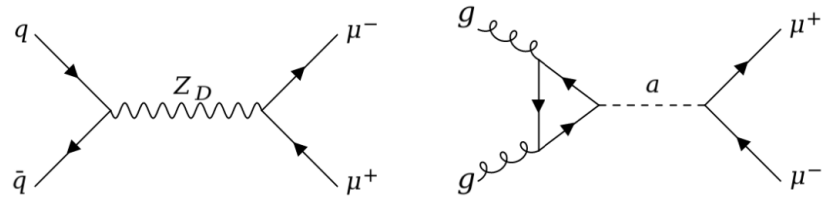
- Keep standard bandwidth -> higher event rates, reduced event information

Dimuon spectrum recorded with scouting trigger



https://twiki.cern.ch/twiki/bin/view/CMSPublic/HLTDiMuon2017and2018

Low-mass dimuon resonances



Signature and physics models

- Prompt low-mass dimuons
- Model-independent limits, and interpretations in models with a dark photon (Z_D) or a BSM pseudoscalar (a) in 2-Higgs-Doublet Model (2HDM+S)

Trigger

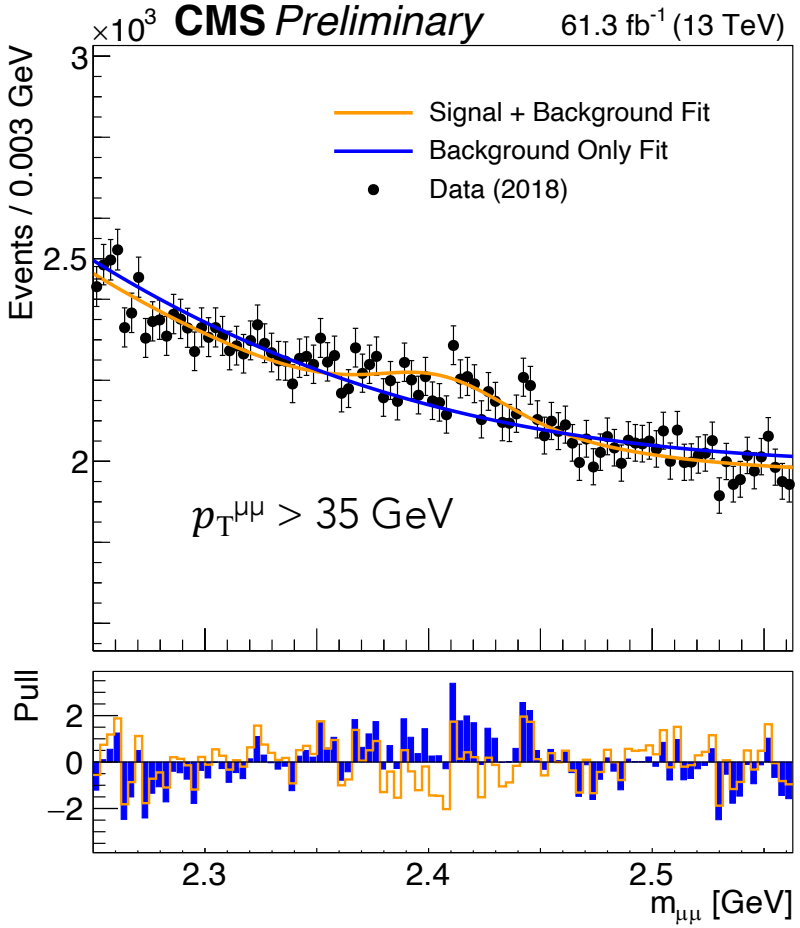
- Scouting trigger for optimized efficiency in very low dimuon-mass regions:
- All event reconstruction performed at HLT
- Muons with $p_T > 3$ GeV recorded, using 4 different L1 triggers
- Event size 4-8 kB, instead of 1 MB for standard dimon triggers
- Rate 2 kHz instead of 0.45 kHz for standard dimuon triggers at peak luminosity

Event selection and analysis

- At least two opposite-charge muons with $p_T > 4$ GeV and $|\eta| < 1.9$ each
- Muons must originate from primary vertex, which must have $L_{xy} < 0.2$ cm from the beam spot
- Mass region around J/ψ, ψ(2S), and Υ(1S) excluded (2.6 – 4.2 GeV)
- MVA μ identification trained with J/ψ and Υ events, using tag & probe method
- Background estimated with probe muon of same charge

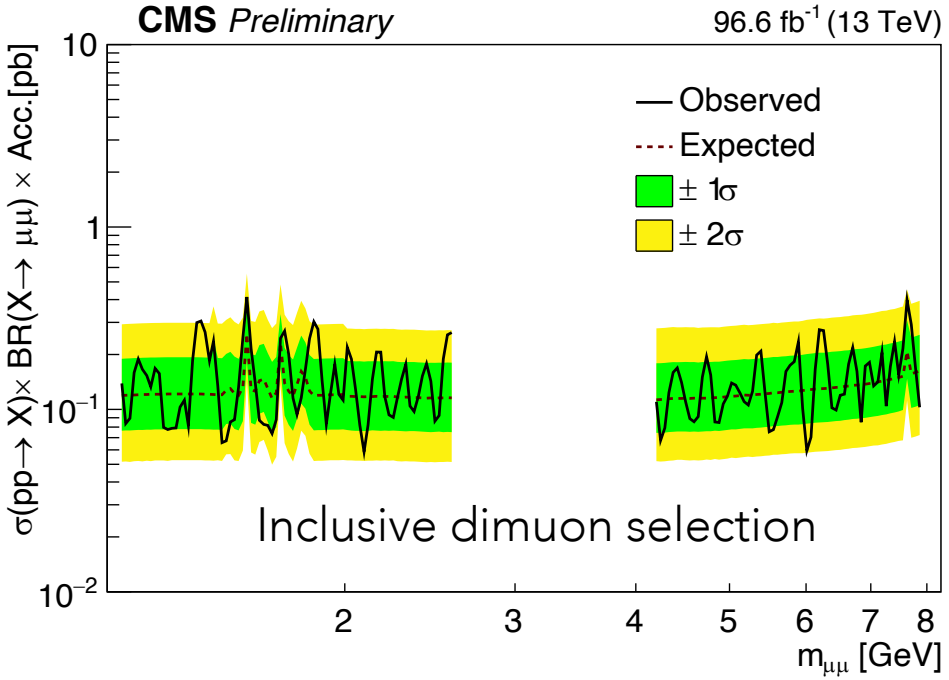
Low-mass dimuon resonances

Fits to dimuon distribution for 2018 data sample



Resonance mass ranges explored:
$1.1 < m_{\mu\mu} < 2.6$, $4.2 < m_{\mu\mu} < 7.9$

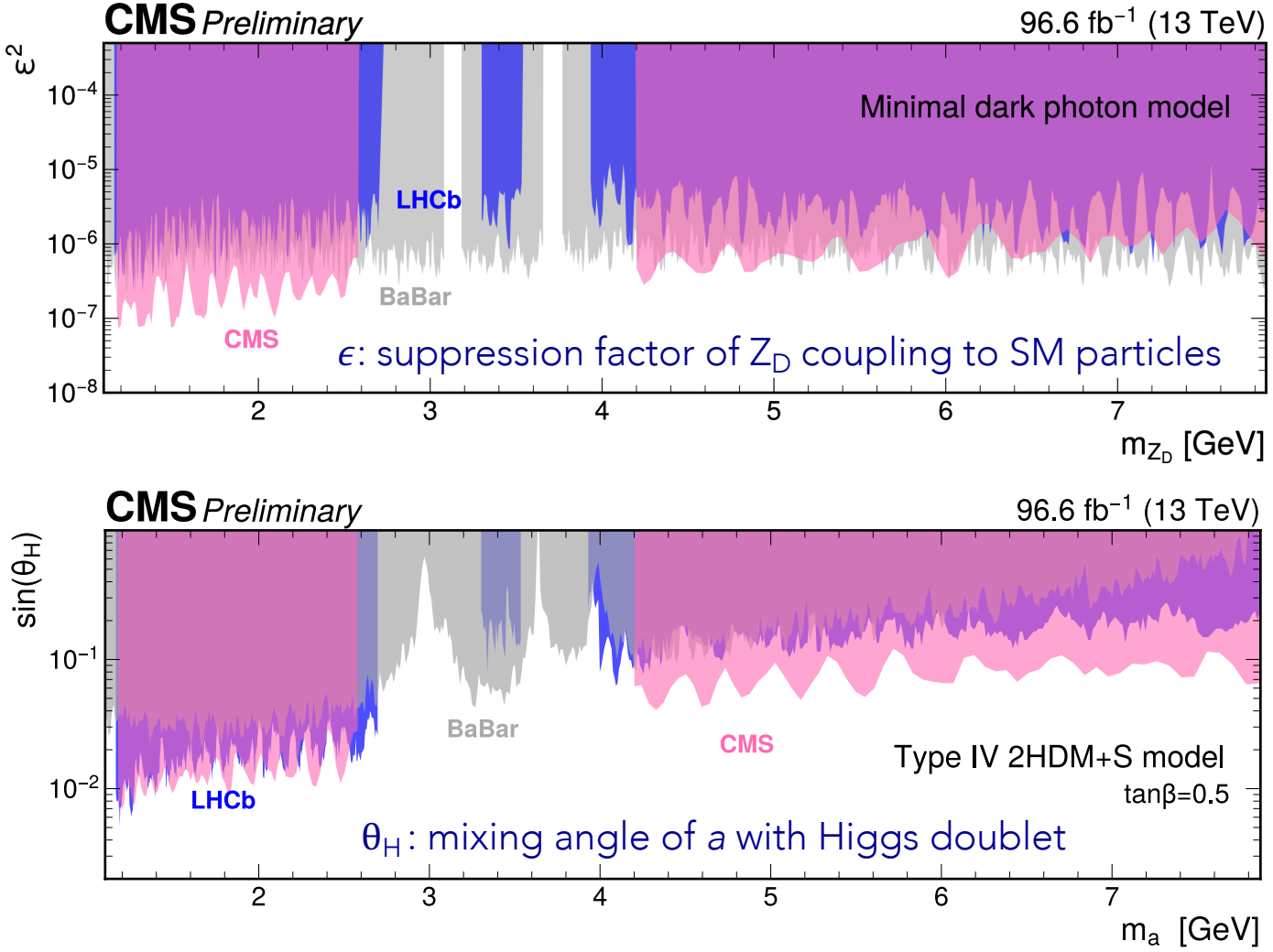
Expected and observed model-independent upper limits at 95% CL on the product of the signal cross section times branching fraction to dimuons



Low-mass dimuon resonances

Limits for physics models presented

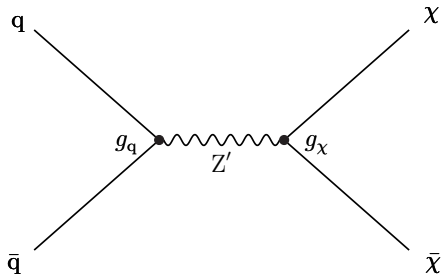
- Competitive with BaBar and LHCb, or even best limits



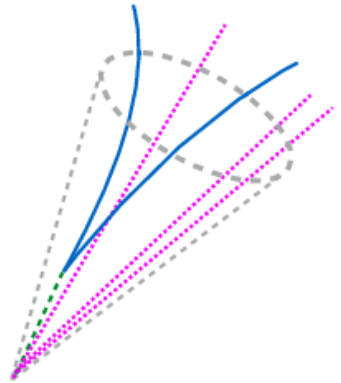
Semivisible jets

PRL 115 (2015) 171804

Physics model



- Hidden sector strongly coupled to SM particles
- Additional *SU(N)* gauge group -> "dark QCD"
- Heavy leptophobic *Z′*
- Semivisible jets: stable dark hadrons (invisible, magenta) and dark hadrons decaying to SM particles (visible, blue)
- r_{inv} : fraction of stable, invisible dark hadrons

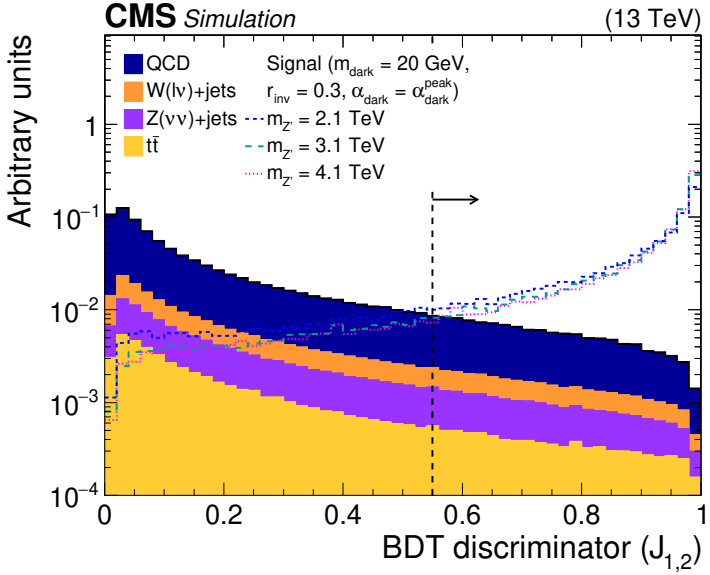


Signature: Wide dijets, with moderate missing E_T aligned with one of the jets

Backgrounds: QCD multijets, $t\bar{t}$, Z($\nu\nu$)+jets, W($\ell\nu$)+jets – from simulation

Analysis strategies

1) Inclusive search based on event-level kinematic variables
2) Boosted decision tree (BDT) discriminator based on 15 jet substructure variables, to distinguish semivisible from SM jets (> 0.55)



Semivisible jets

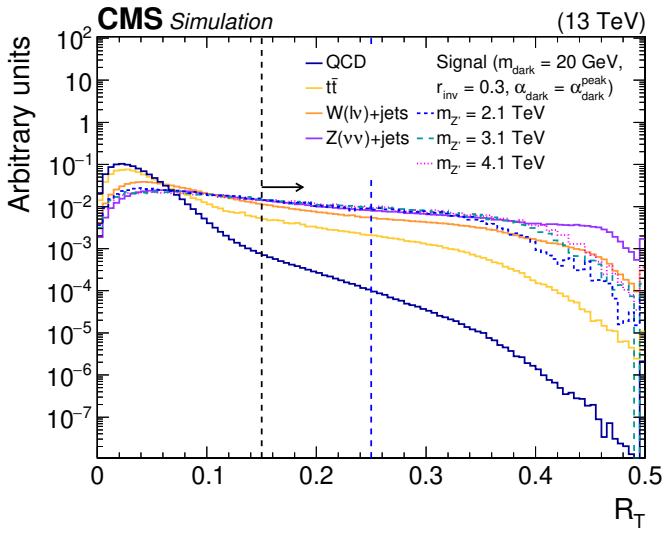
Event selection

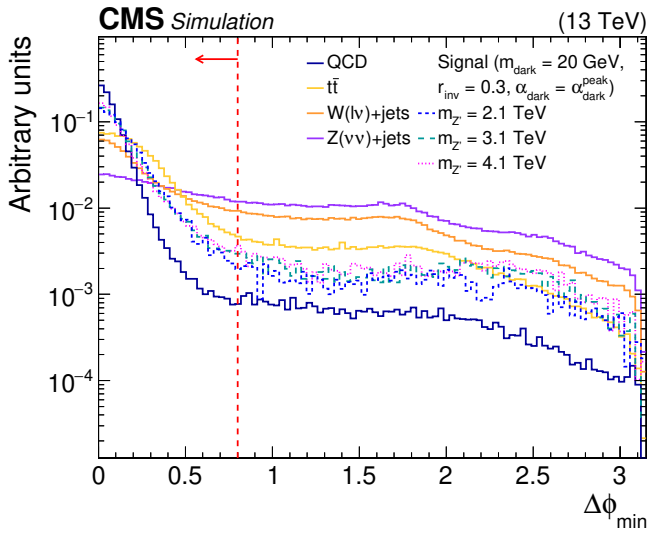
- Key selection variable m_{T} : kinematic peak with endpoint at *Z'* mass, for signal, and falling spectrum for background

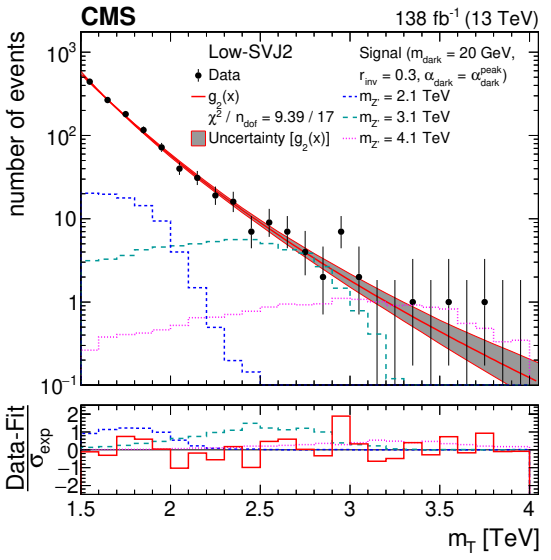
$$m_{\mathrm{T}} = m_{\mathrm{JJ}}^2 + 2p_{\mathrm{T}}^{\mathrm{miss}}\left[E_{\mathrm{T,JJ}} - p_{\mathrm{T,JJ}}\cos(\Phi_{JJ,\mathrm{miss}})\right]$$

- Transverse ratio $R_{\mathrm{T}} = p_{\mathrm{T}}^{\mathrm{miss}} / m_{\mathrm{T}} > 0.15$, to decorrelate $p_{\mathrm{T}}^{\mathrm{miss}}$ from m_{T}

- Minimum angle between jets and $p_{\mathrm{T}}^{\mathrm{miss}}$, to align jets and $p_{\mathrm{T}}^{\mathrm{miss}}$:
  $\Delta\Phi_{\mathrm{min}} = min\,[\Delta\Phi(\boldsymbol{p}_{J1}, \boldsymbol{p}_{\mathrm{T}}^{\mathrm{miss}}), \Delta\Phi(\boldsymbol{p}_{J2}, \boldsymbol{p}_{\mathrm{T}}^{\mathrm{miss}})] < 0.8$







Semivisible jets

Results from inclusive (left) and BDT (right) searches, at 95% CL

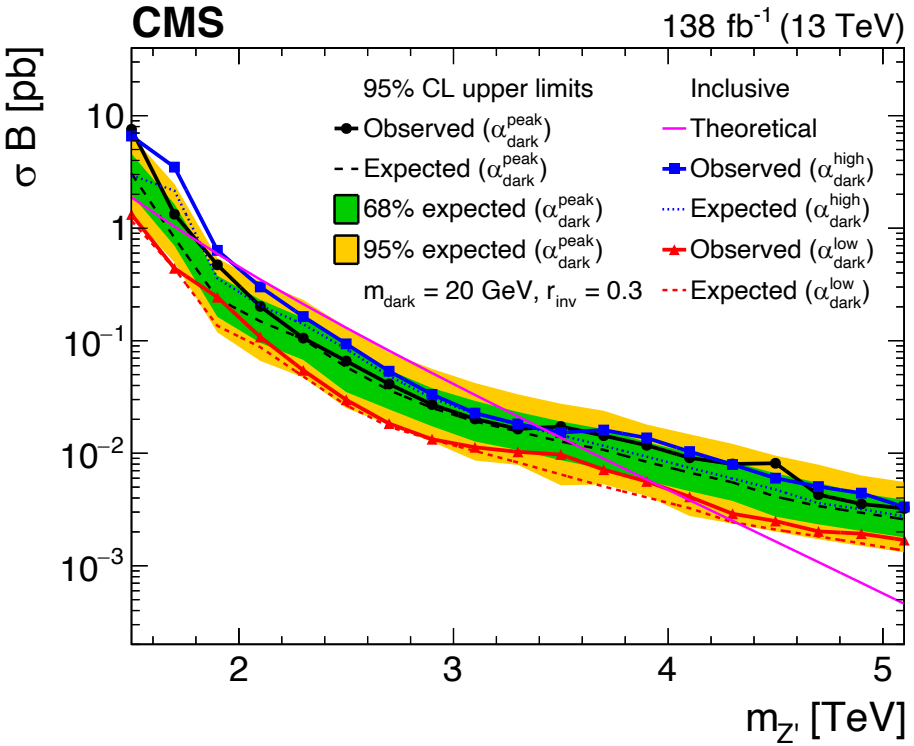
BDT-tagging of semivisible jets reduces the background by ~O(2)

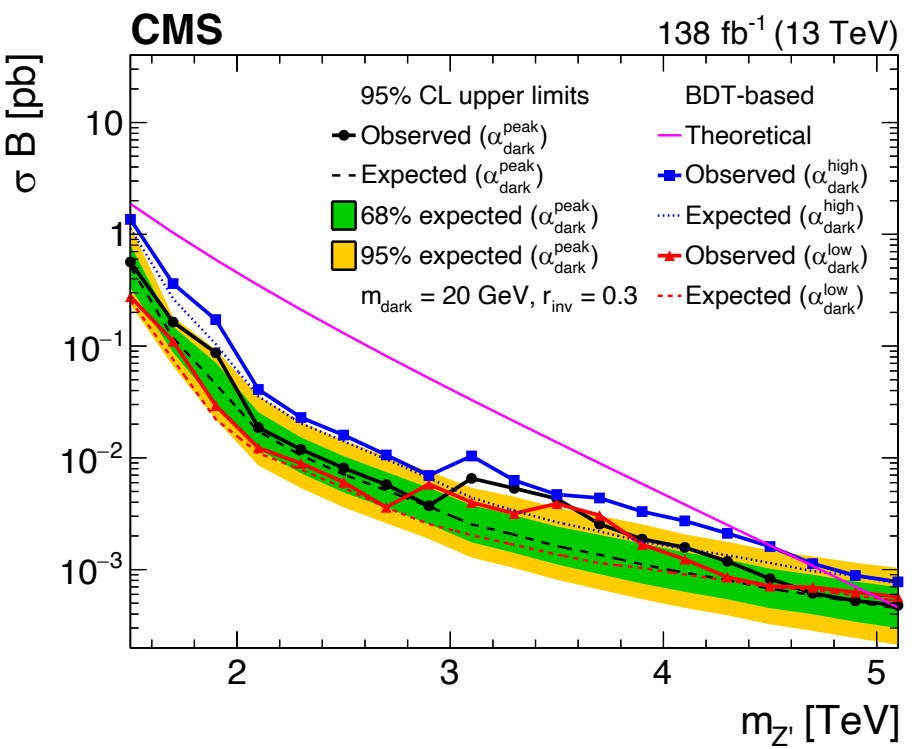
r_{inv} = 0. 3: 1.5 < $m_{Z'}$ < 4.0 TeV

m_{dark} = 20 GeV: 0.07 < r_{inv} < 0.53

r_{inv} = 0. 3: 1.5 < $m_{Z'}$ < 5.1 TeV

m_{dark} = 20 GeV: 0.01 < r_{inv} < 0.77





Dark Higgs (WW) + missing transverse momentum

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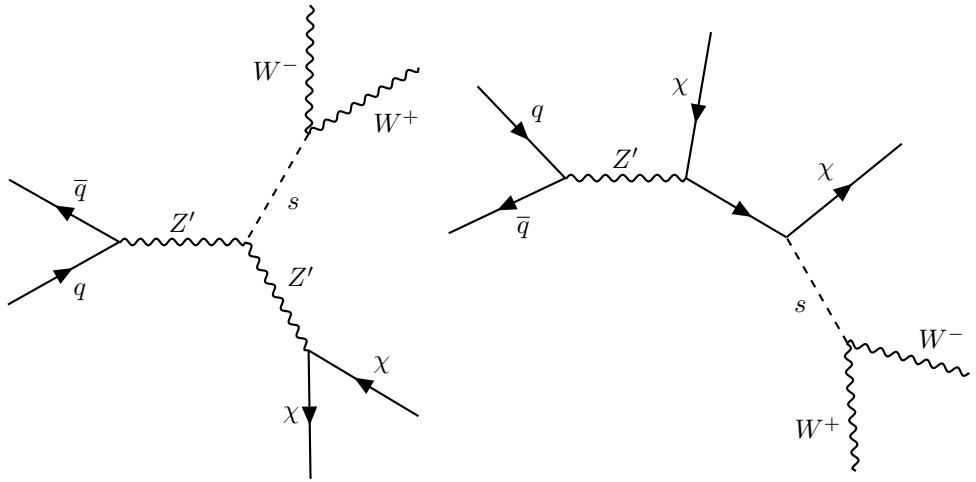
Physics model and signature

- Dark Higgs boson *(s)* simplified model, with *s* mass above W^+W^- mass threshold, and *Z'* mediator
- Model parameters considered:

  160 GeV < m_s < 400 GeV, 200 GeV ≤ $m_{Z'}$ < 2500 GeV, 100 GeV < m_χ < 300 GeV
  Z' couplings: $g_\chi = 1$, $g_q = 0.25$
  Mixing angle between SM and dark Higgs bosons: $\sin\theta = 0.01$
- Isolated leptons (e or μ) from W decays, missing transverse momentum
- Di-leptonic (2 leptons from W decays) and semileptonic channels (1 lepton and jets from W decays)
- No b-tagged jets, to reduce tW and $t\bar{t}$ backgrounds



Dark Higgs (WW) + missing transverse momentum

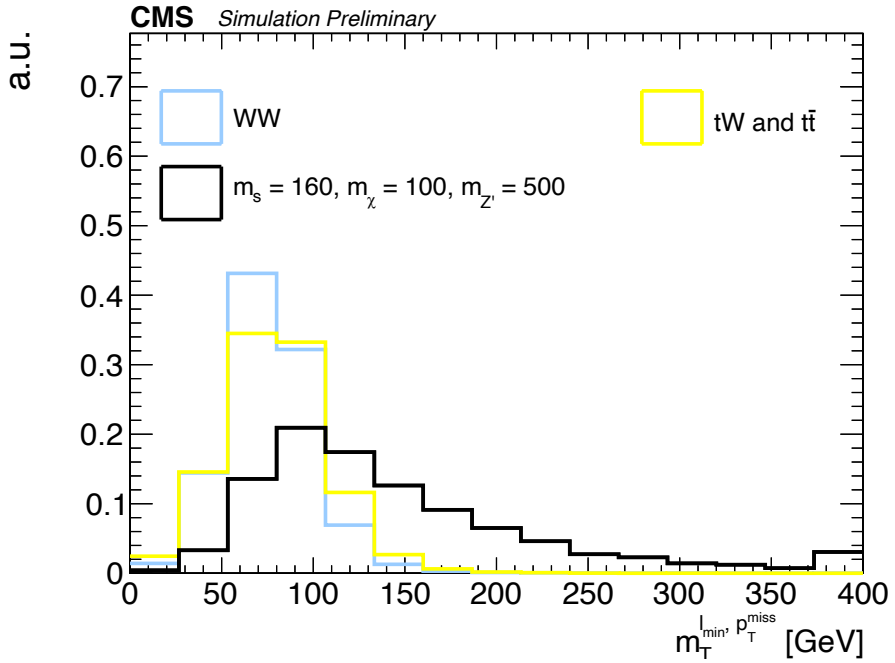
Di-leptonic channel

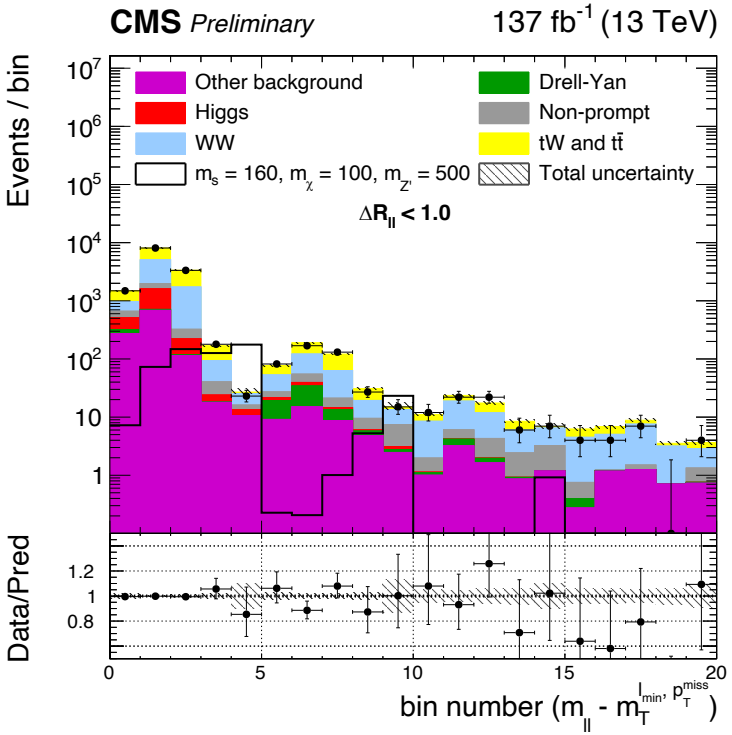
- 2 isolated leptons with different flavours and charges,
  $p_T^{\ell\,\max} > 25$ GeV, $p_T^{\ell\,\min} > 20$ GeV, $p_T^{\text{miss}} > 20$ GeV $m_{\ell\ell} > 20$ GeV, $p_T^{\ell\ell} > 30$ GeV,
  $\Delta R_{\ell\ell} < 2.5$ (proxy for boost, e.g. high boost for $\Delta R_{\ell\ell} < 1.0$)
  Key variable: transverse mass of trailing lepton and p_T^{miss}

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

2D-distribution: $m_{\ell\ell}$ - $m_T^{\ell\,\min, p_T^{\text{miss}}}$

Unrolled distribution:



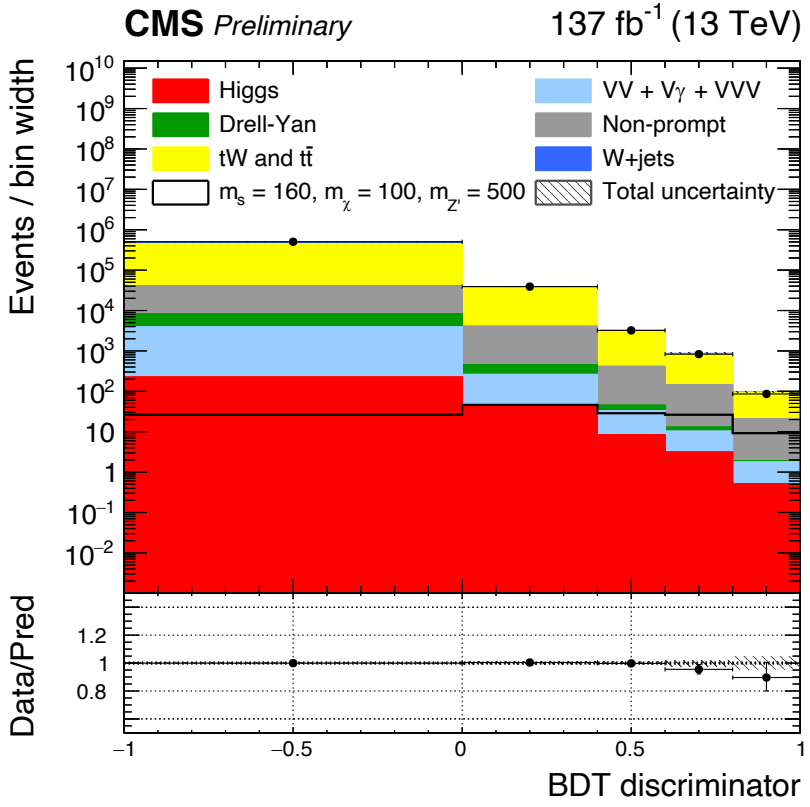


Dark Higgs (WW) + missing transverse momentum

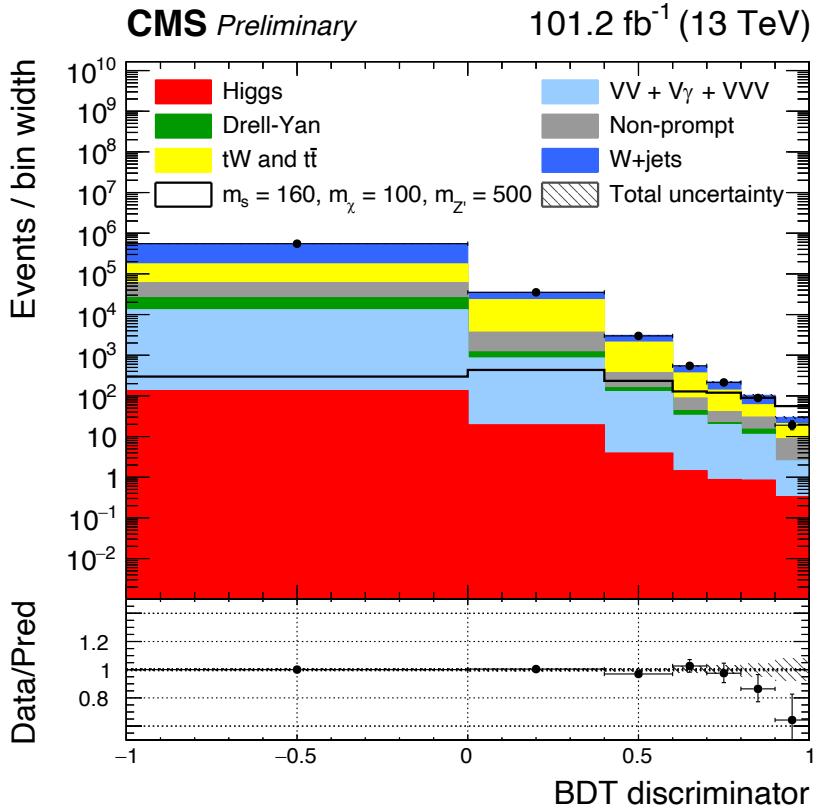
Semi-leptonic channel

- 1 isolated lepton, p_T^{miss}, ≥ 2 jets, 2 compatible with W
  Key variable: BDT discriminator with 13 variables

top control region (events with b jets)

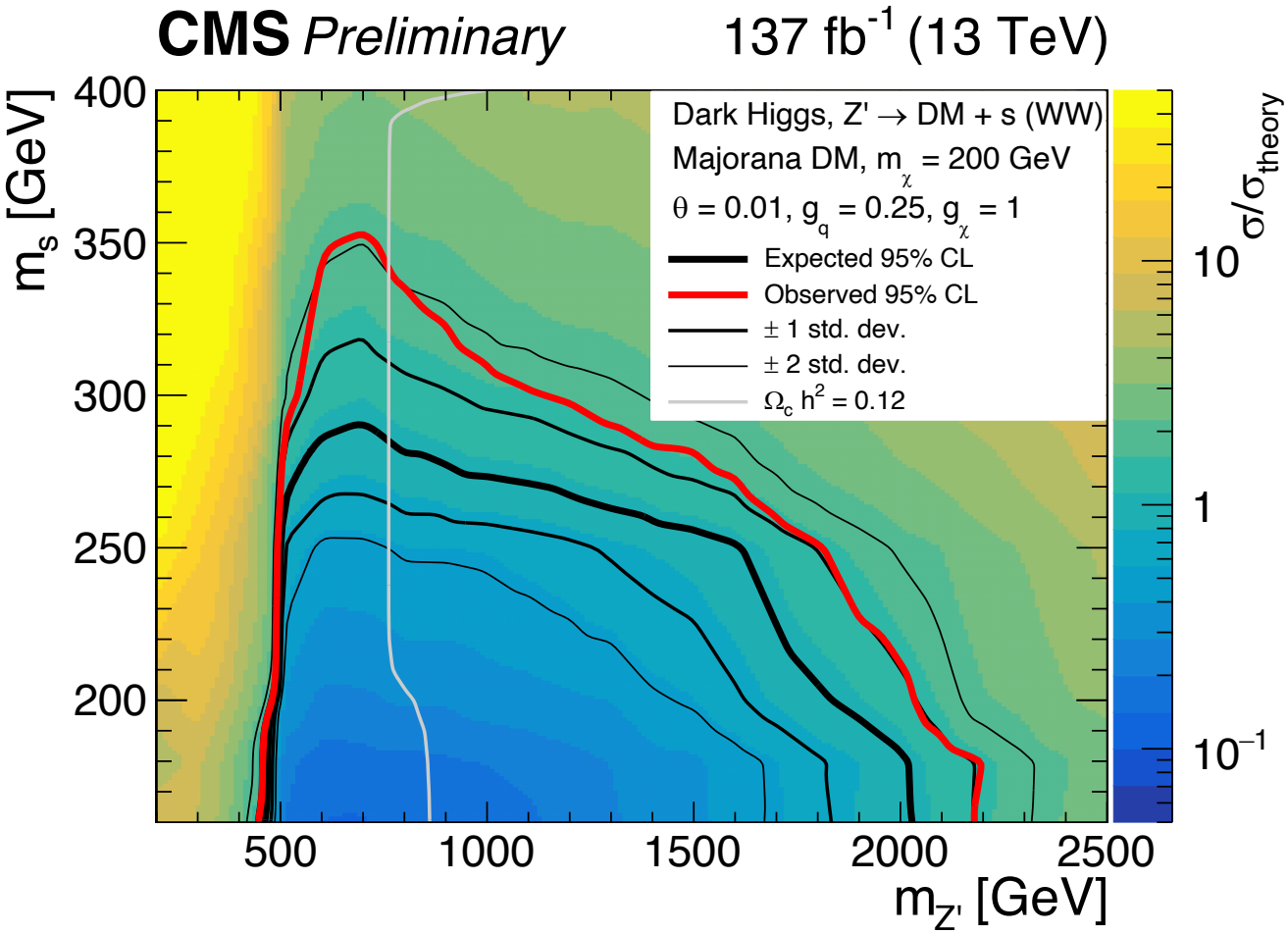


Signal region



Dark Higgs (WW) + missing transverse momentum

Most stringent 95% CL limits, for $m_\chi = 200$ GeV :
$m_s = 160$ GeV: Z' masses up to 2200 GeV excluded
$m_{Z'} = 700$ GeV: s masses up to 350 GeV excluded



Conclusions

- Searches for hidden sector increasingly important
- Full LHC Run 2 dataset explored
- No evidence for hidden sector particles found yet, but Run 3 data will provide more opportunities
- Machine learning and new analysis techniques will enhance discovery potential

I always believed in leaving no stone unturned

Arnold Schwarzenegger