Searches in CMS for Long-lived Particles (LLPs) and other non-conventional signatures

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LLPs in BSM

LLPs are **predicted in many BSM physics** scenarios in **particular regions of the model phase space**

For this, the **matrix element and/or phase space must be small**

$$\frac{1}{\tau} = \Gamma = \frac{1}{2m}\int d\Phi_f |M|^2 \sim \frac{\epsilon^2}{(8\pi)^{a-1}} \frac{m^n}{M^{n-1}}$$

arXiv:2212.03883

- Decays via heavy virtual mediator (m << M)
  - e.g Heavy Neutral Leptons, split SUSY
- Small mass splitting
  - e.g Inelastic dark matter, compressed SUSY
- Suppressed couplings
  - e.g Dark sectors, freeze-in, RPV SUSY

These mechanisms exist in SM, why not in BSM?

- We don't know if they exist, **data will tell**

Outline

CMS searches target a wide range of LLPs signatures defined by different **cτ**, **charge** and/or **decay products**

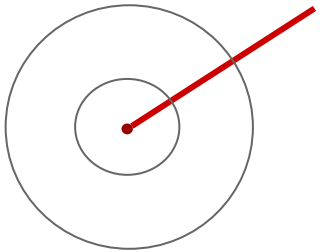
- This talk focuses on **recent CMS results for LLP**

New result!

Two Run 3 results!

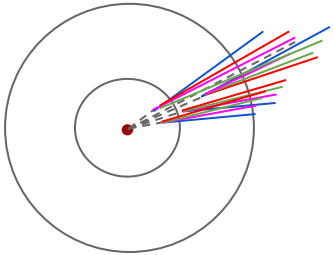
Heavy Stable Charged Particles (HSCP)
CMS-PAS-EXO-18-002

13 TeV



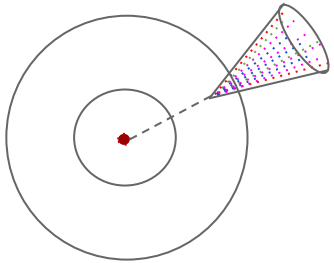
Emerging jet
CMS-EXO-22-015

13 TeV



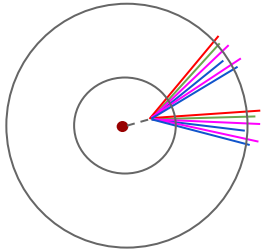
Muon detector showers
CMS-PAS-EXO-23-015

13 TeV



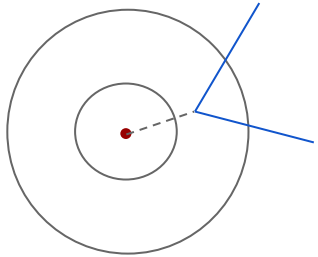
Displaced dijet
CMS-PAS-EXO-23-013

13.6 TeV



Displaced dilepton
CMS-EXO-23-014

13.6 TeV



13 TeV : Run 2 (2016-2018)
13.6 TeV : Run 3 (2022-Ongoing)

*Schematic views for illustration purposes

- All other results: **https://cms-results.web.cern.ch/cms-results/public-results/publications/EXO/LLP.html**

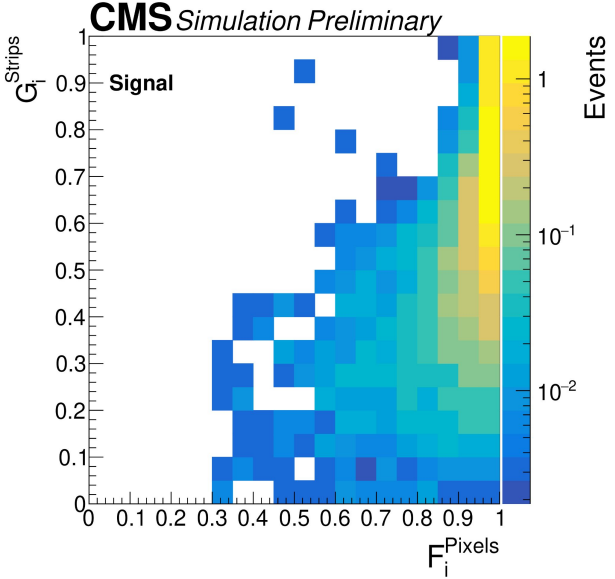
Heavy Stable Charged Particles (I)

CMS-PAS-EXO-18-002 **13 TeV**

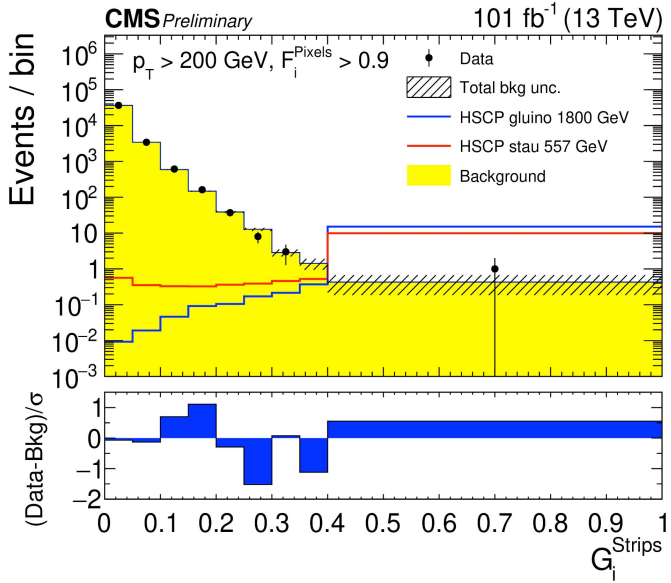
Signature is a high p_T isolated track **with large ionization (dE/dX) in the silicon tracker**

- Predicted in **any BSM containing stable charged particles**
- ATLAS, JHEP 06 (2023) 158, reported a 3.3 global excess for a target mass of 1.4 TeV

Two **dE/dX** discriminant variables, G_i^{Strip} and F_i^{Pixel}:



Large for signal



Uncorrelated for background

- Used in ABCD to predict background

Heavy Stable Charged Particles (I)

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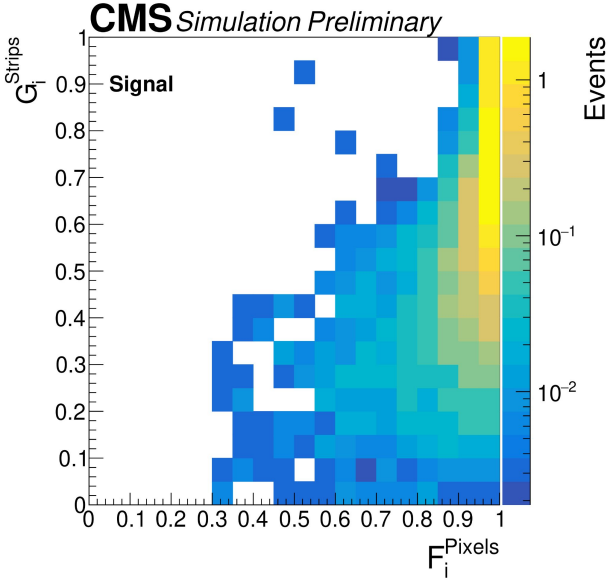
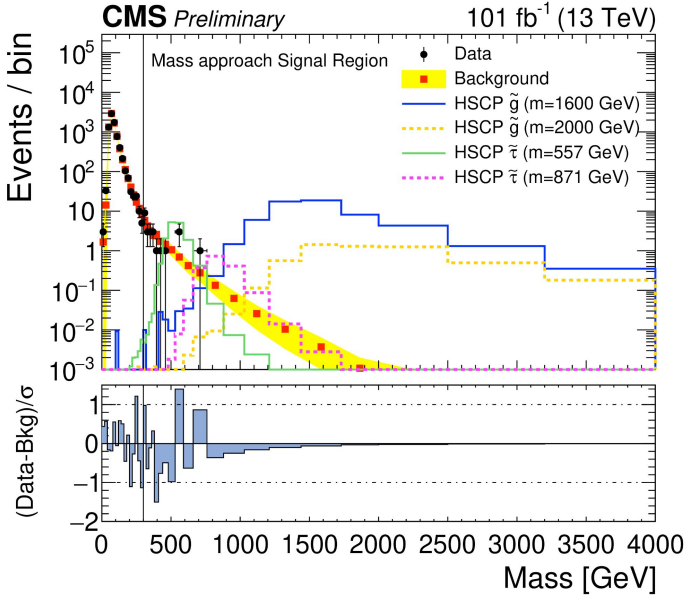


Large for signal

Alternative approach using mass spectrum:



No excess

Heavy Stable Charged Particles (II)

CMS-PAS-EXO-18-002 13 TeV

Multiple interpretations: $\tilde{t}, \tilde{g}, \tilde{\tau}, |Q| = 1e, 2e$

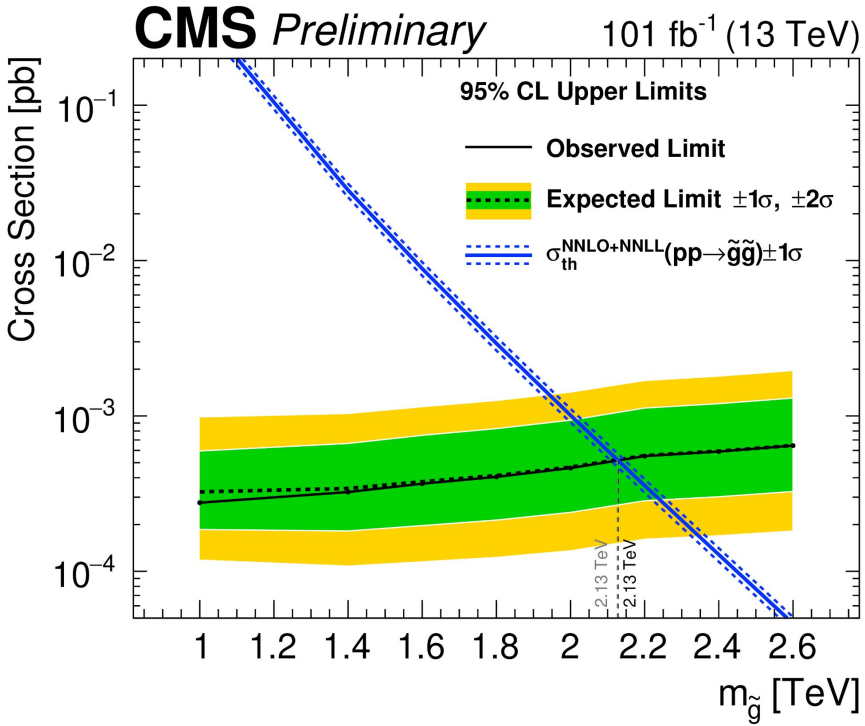
ATLAS excess corresponds to $\sigma(\tilde{g}\tilde{g})$ = 0.59 fb at 1.4 TeV

- $\sigma(\tilde{g}\tilde{g})$< 0.32 fb excluded at 95% C.L

If the signal is due to $Z' \rightarrow \tau'^{,2e}\tau'^{,2e}$ with m($\tau'^{,2e}$) = 600 GeV and m(Z′) = 5 TeV, [JHEP 08 (2022) 12]

- σ(Z′) < 0.03 fb excluded at 95% C.L

ATLAS excess is not confirmed by CMS

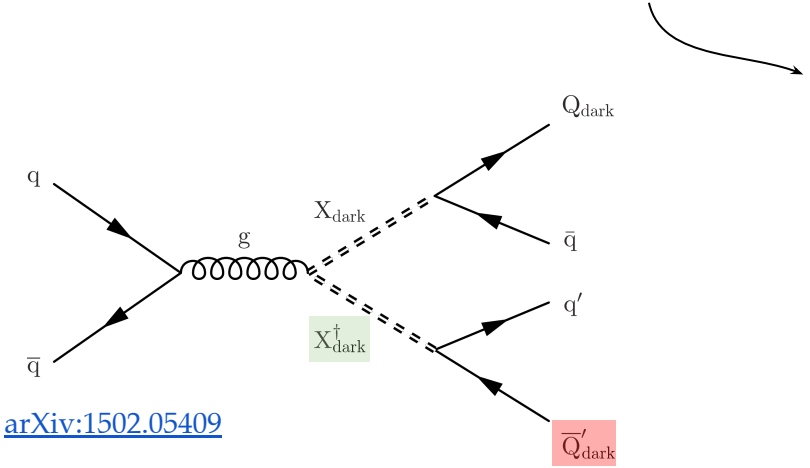


Emerging jets (I)

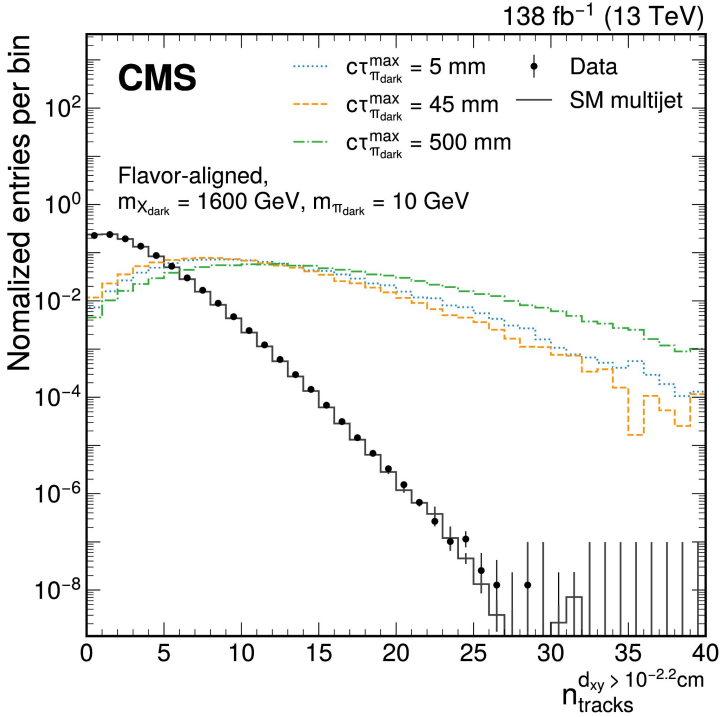
CMS-EXO-22-015 **13 TeV**

Signature is **multiple displaced vertices** produced in the hadronization of a dark QCD sector

- Dark mediator, X_{dark}, charged under dark QCD and QCD
- Dark fermions, Q_{dark}, that hadronize and form dark jets containing dark hadrons, $\pi^{\pm}_{dark}$
  - $\pi^{\pm}_{dark}$ is long-lived and decays back to SM particles



arXiv:1502.05409



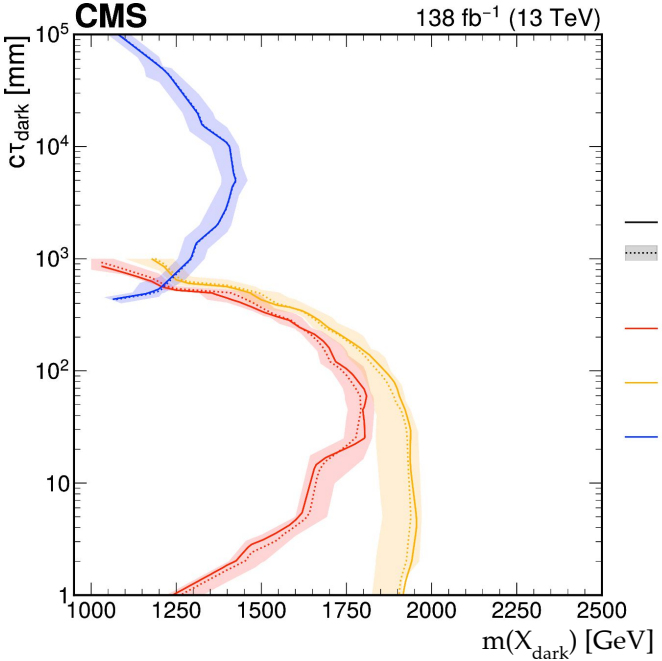
Free parameters: $m(X_{dark})$, $m(\pi^{\pm}_{dark})$, $c\tau(\pi^{\pm}_{dark})$

- Unflavored, X_{dark} couples to d
- Flavor-aligned, X_{dark} couples to d, s, b

Emerging jets (II)

CMS-EXO-23-005 CMS-EXO-22-015 **13 TeV**

Two strategies: Cut and Count (model agnostic) and Graph Neural Network (GNN)



If $c\tau(\pi_{dark}) \lesssim 1m$, the signature becomes a muon detector shower [CMS-EXO-21-008]

- GNN significantly improves the sensitivity for $c\tau(\pi_{dark}) \lesssim 100$ mm
- New result surpass previous publication, [CMS-EXO-18-001], with 16.1 fb^{-1} by $m(X_{dark}) \approx 500$ GeV

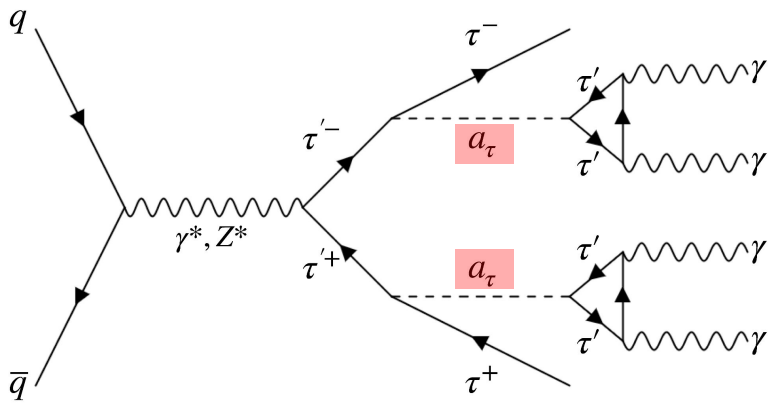
New result!

Search for Vector-like leptons with LLP decays (I)

CMS-PAS-EXO-23-015 13 TeV

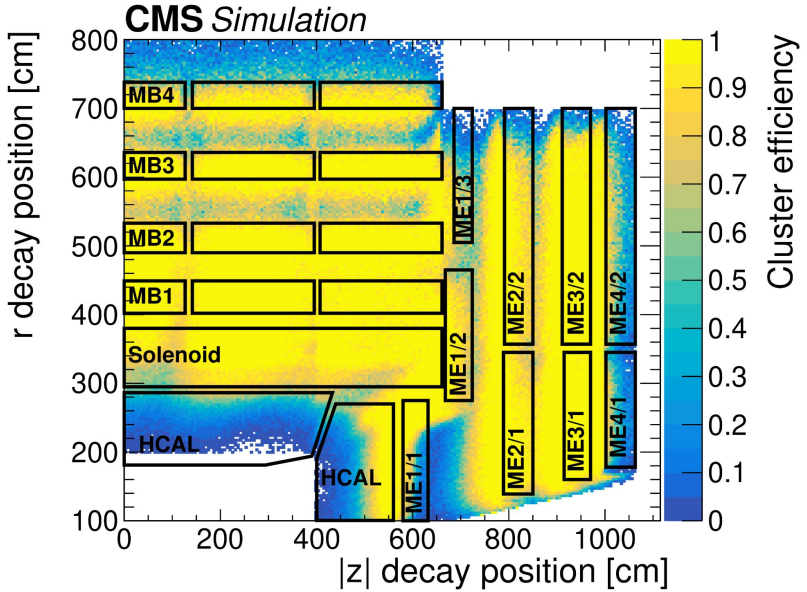
Signature is **at least one prompt τ lepton and one muon detector shower (MDS)**

- Predicted in vector-like lepton (VLL) decays: $\tau' \rightarrow \tau\, a_\tau$
  - τ' produced via electroweak interactions
  - a_τ is light and long-lived



a_τ decays can induce an electromagnetic shower with **cluster of large hit multiplicity, N_{hit}**

- MDS were previously used in CMS (e.g CMS-EXO-22-017 and CMS-EXO-21-008)

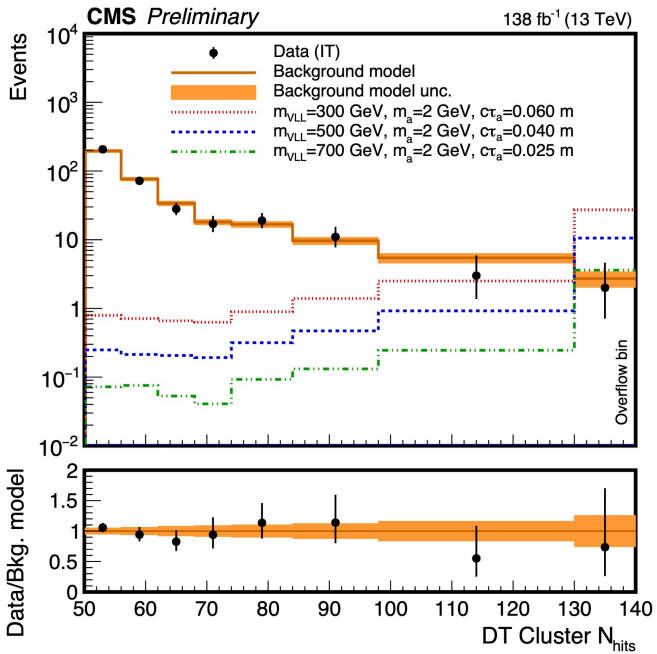


New result!

Search for Vector-like leptons with LLP decays (II)

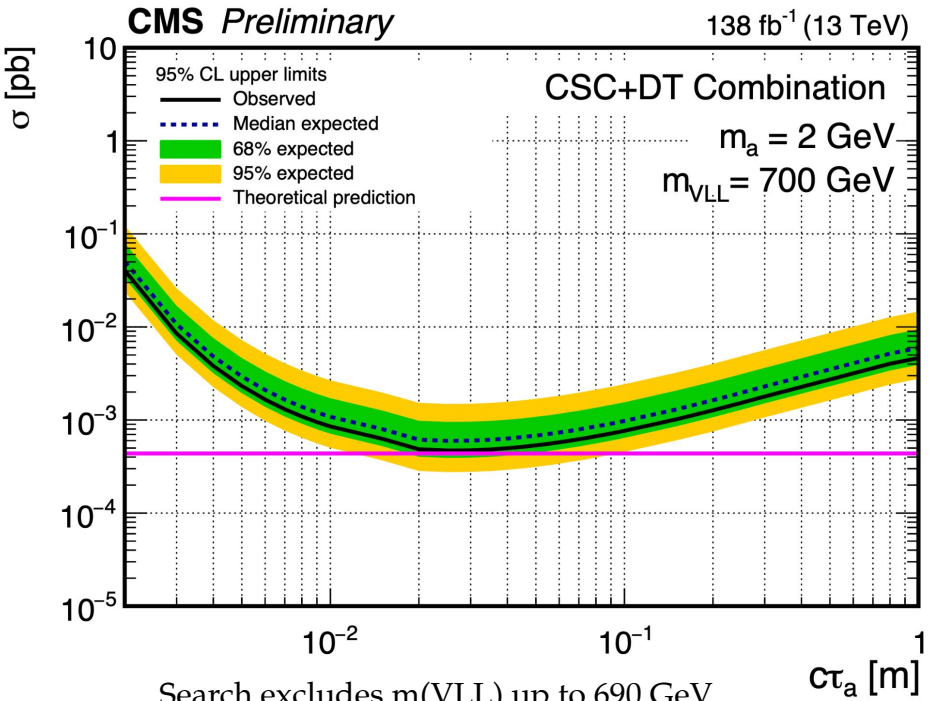
CMS-PAS-EXO-23-015 13 TeV

Signal regions split by clusters in DT and CSC



N_{hits} shape from events failing τ identification

- Normalization from fit to data
- Validated in out-of-time data



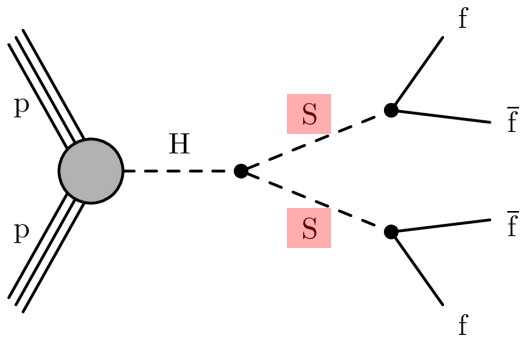
Search excludes m(VLL) up to 690 GeV, depending on $c\tau(a_\tau)$, for $m(a_\tau)$ = 2 GeV

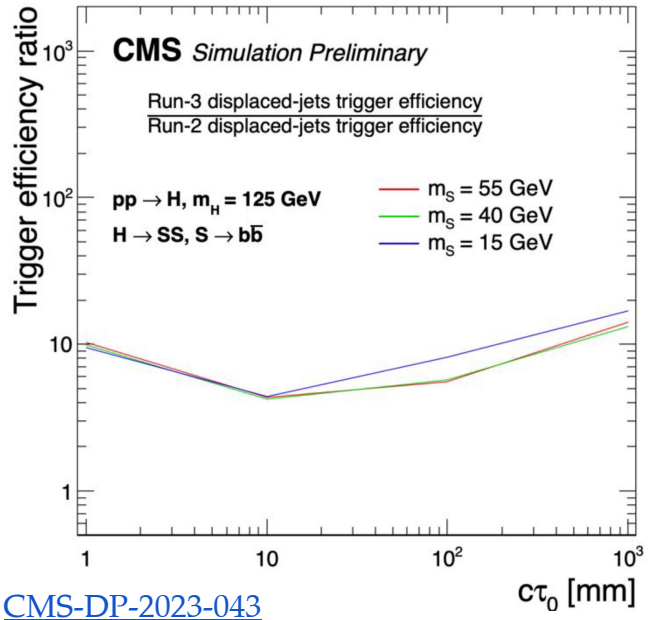
Displaced dijet (I)

CMS-PAS-EXO-23-013 **13.6 TeV**

Signature is **displaced tracks and vertices** with 34.7 fb^{-1} at 13.6 TeV

Compared to Run 2, **improved sensitivity at low LLP mass** (e.g for h(125) → SS)



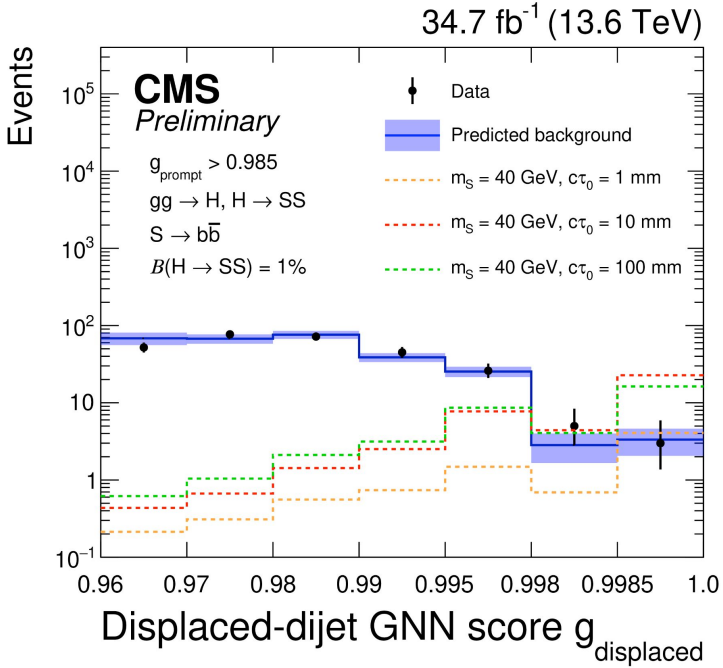


CMS-DP-2023-043

1. Improved triggers:
Factor 4-10 gain in trigger efficiency in signal

Displaced dijet (II)

CMS-PAS-EXO-23-013 **13.6 TeV**



2. Improved vertex reconstruction combined with better discrimination thanks to GNNs:

Two GNN that cover complementary features of LLP decay

- $g_{displaced}$: tracks with $d_{xy} > 0.5$ mm, $d_{xy}/\sigma(d_{xy}) > 5$, and secondary vertices
- g_{prompt} : tracks with $d_{xy} < 0.3$ mm

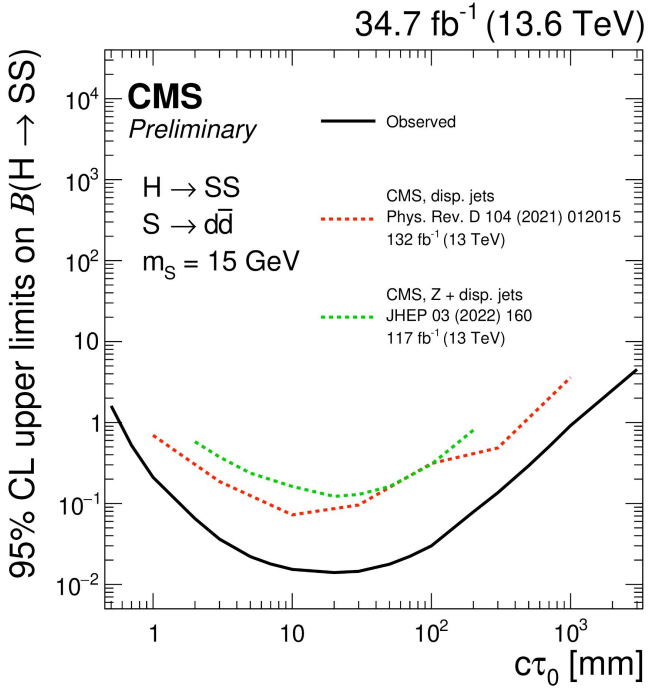
Both GNNs are uncorrelated

- Used for background evaluation in ABCD method

Displaced dijet (III)

CMS-PAS-EXO-23-013 **13.6 TeV**

Up to a **factor 10 improvement** compared previous search, [CMS-EXO-19-021], with a **~4 times smaller dataset!**

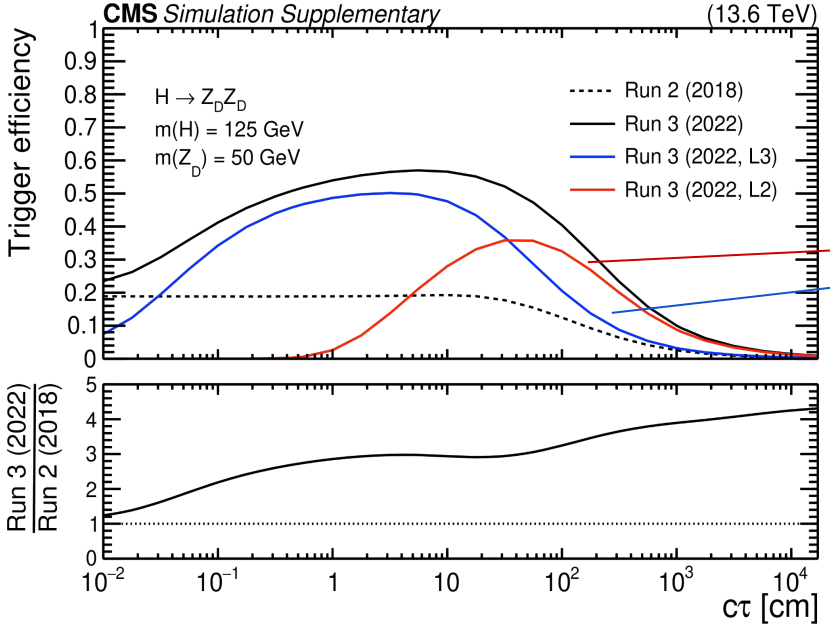


Best limits to date to B(H → SS) for m(S) between 15 and 55 GeV and 0.1 mm ≲ $c\tau$ ≲ 1 m

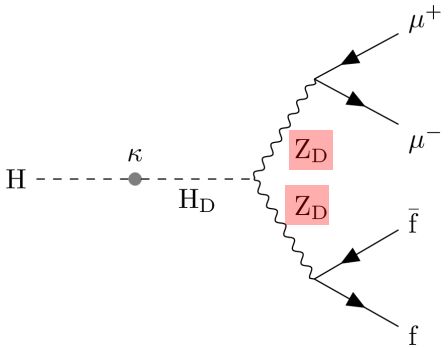
Displaced dimuons (I)

CMS-EXO-23-014 **13.6 TeV**

Inclusive search with 36.6 fb^{-1} at 13.6 TeV for LLPs decaying into **displaced dimuons within and beyond the silicon tracker** with improved triggers for Run 3



New triggers with lower p_T thresholds **improve the trigger efficiency for H → $Z_D Z_D$ up to a factor 4 wrt previous result** [CMS-EXO-21-006]

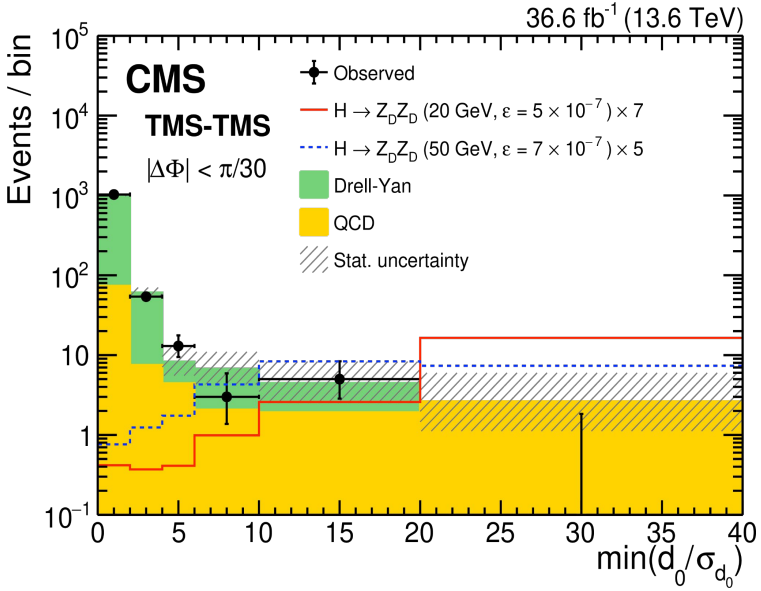


Displaced dimuons (II)

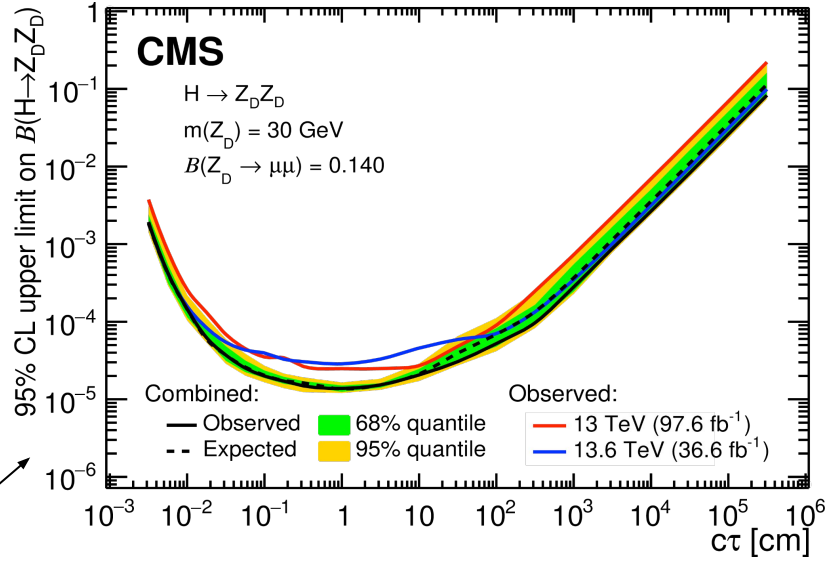
CMS-EXO-23-014 **13.6 TeV**

Search uses dimuons reconstructed in

- **Tracker + muon system** (TMS-TMS)
- **Muon system only** (STA-STA)



- TMS-TMS + STA-STA combination leads to **sensitive to a wide range of cτ from μm to km!**



- After 13 TeV + 13.6 TeV combination, **~2 stronger constraints on B(H → $Z_D Z_D$) wrt previous result**
  - With a ~2.5 smaller dataset at 13.6 TeV!

Wrap-up

Presented latest results on LLP searches from CMS

- ATLAS excess not confirmed by recent HSCP search
- New emerging jet search with x4 more data, and improved sensitivity at short cτ thanks to ML
- New signature: prompt τ + muon detector shower
- First 13.6 TeV results significantly improve over 13 TeV results with 2.5-4x less data, thanks to the deployment of innovative triggers and refined analysis strategies

Exciting LLP results with 13.6 TeV data coming soon

- New LLP triggers, CMS-DP-2023-043
- Better scouting and parking, CMS-EXO-23-007
- Plenty of lessons learned from Run 2