

Searches for non-conventional signatures at CMS

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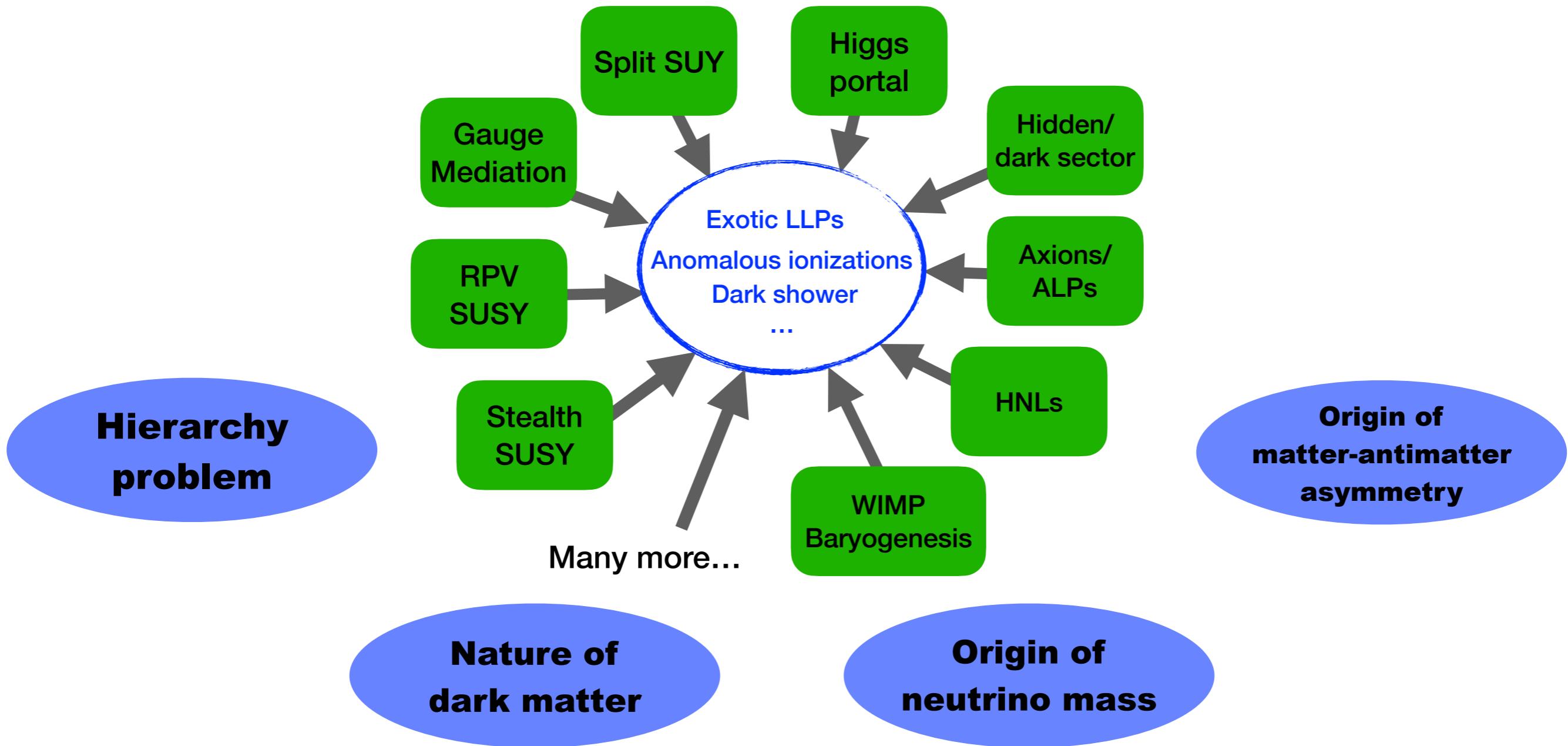
On behalf of the CMS Collaboration

Pheno 2023

May. 9th, 2023

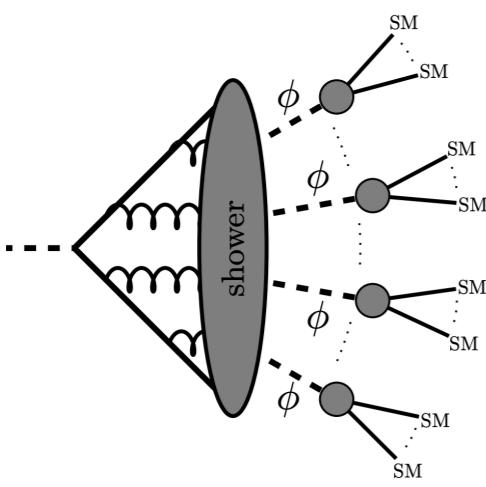
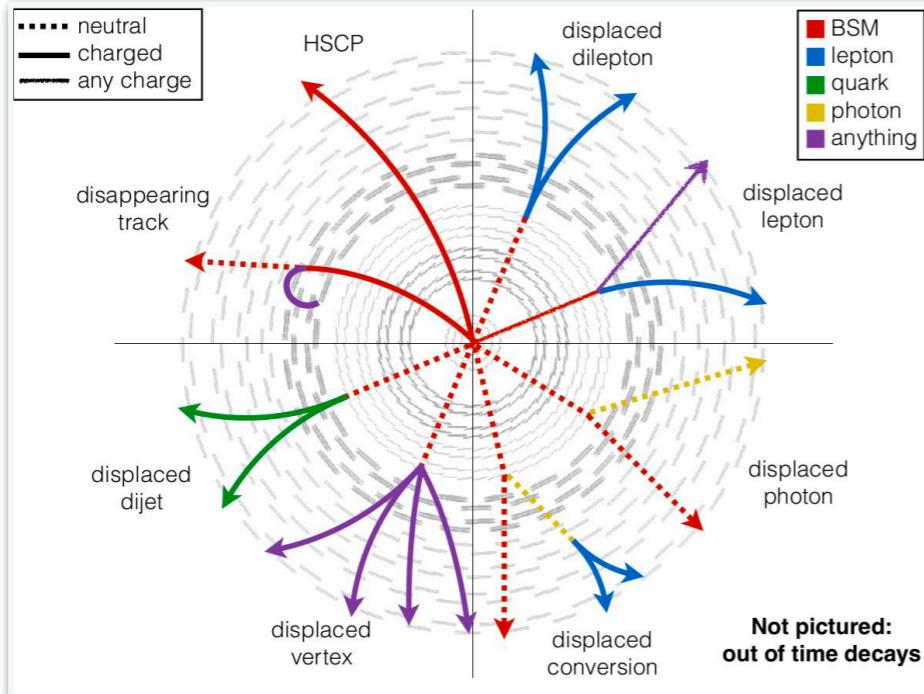
Non-conventional signatures

- ❖ **Non-conventional signatures** (exotic long-lived particles, anomalous ionizations, semi-visible jets, soft unclustered energy patterns, etc.) can naturally arise from many BSM scenarios.



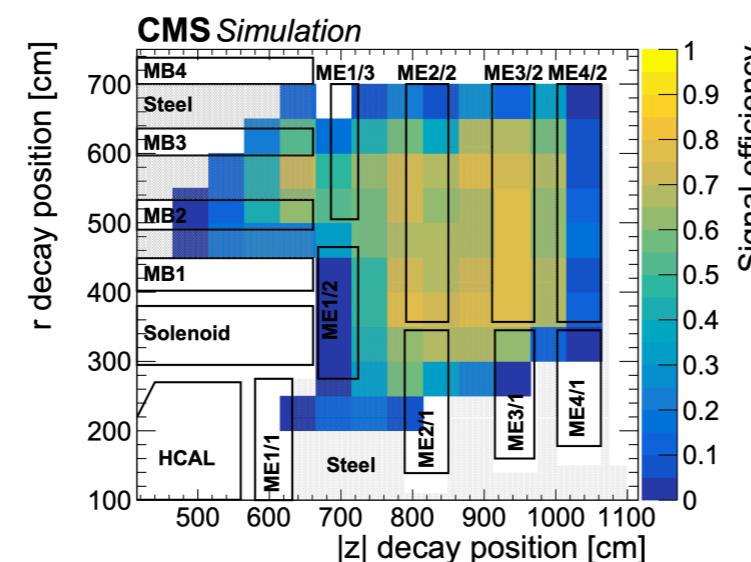
Experimental challenges

Rich experimental signatures



Dark shower:

Emerging jets, semivisible jets, SUEPs,



Shower in the muon system

Displaced jets search

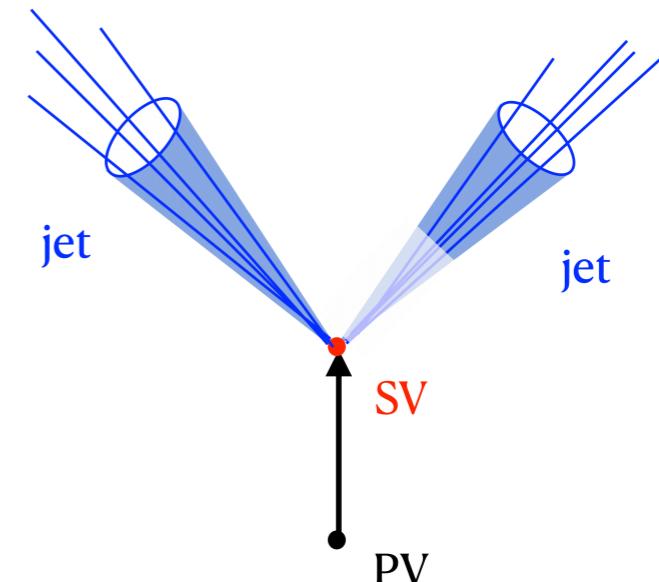
- ❖ **Search for hadronic decays of LLPs inside the inner tracking system (full Run-2 data)**

- The **flagship LLP search** at CMS;
- **Highly model independent** – world-leading sensitivities to a large variety of LLP models

[arXiv: 2012.01581]

(J.L. CERN EP-LHC seminar: [link](#))

- Dedicated displaced-jets triggers to lower H_T threshold at HLT (from $\sim 1000\text{GeV}$ to $\sim 400\text{GeV}$);
- Search for **1 displaced vertex** accompanied with **2 non-prompt jets**;
- Multivariate discriminant (gradient BDT) based on customized variables to separate LLP signatures from background;
- Sensitive to **a large variety of LLP models**.



- Dedicated displaced vertex reconstruction using displaced tracks associated to two jets;
- Relations between the displaced vertex, displaced/prompt tracks, and the jets are exploited to identify LLP decays.

Displaced jets search

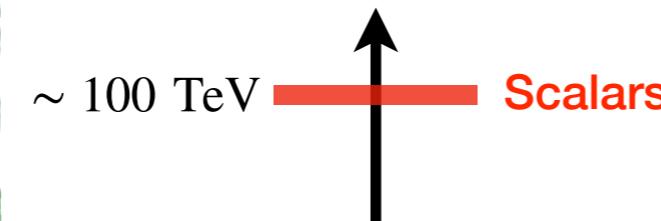
- ❖ Expected 0.75 event in the final signal region, observed 1 event
 - Set currently the best limits on a large number of LLP models

Signal interpretations

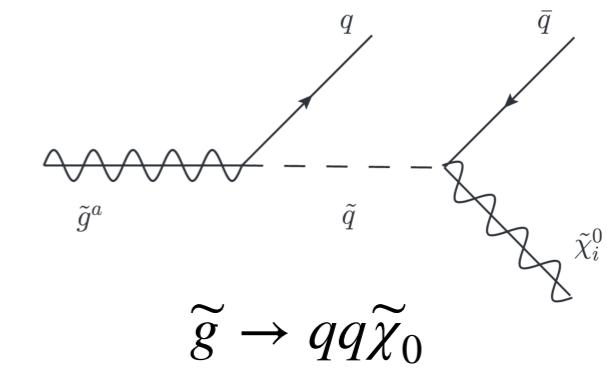
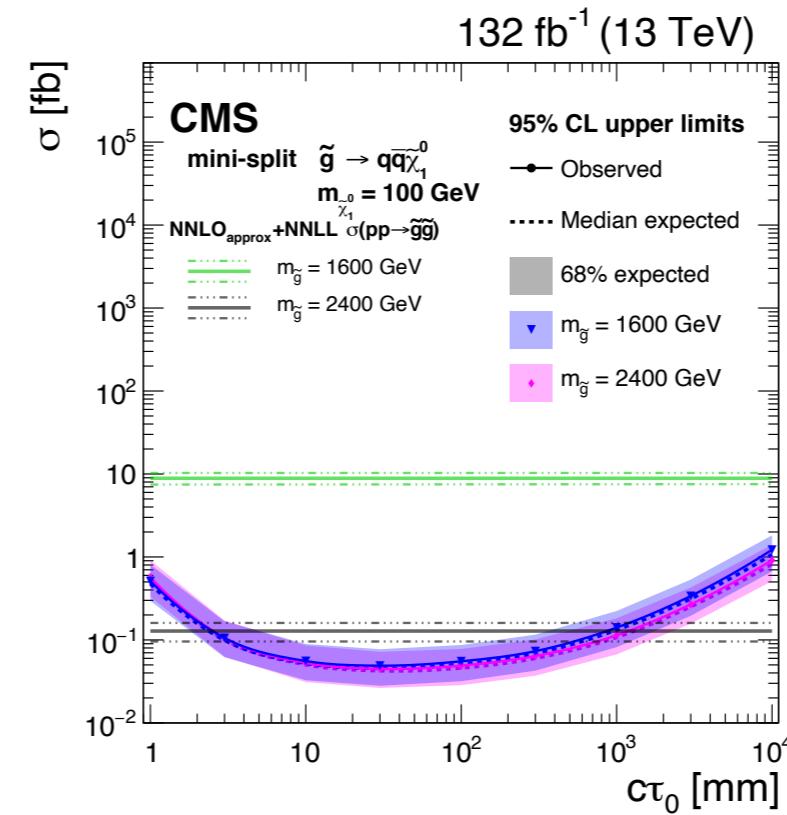
- Exotic Higgs decays:
 - 125 GeV $H \rightarrow SS, S \rightarrow bb/dd$
- Split SUSY: $\tilde{g} \rightarrow q\bar{q}\tilde{\chi}_0$
- Gauge mediation: $\tilde{g} \rightarrow g\tilde{G}$
- RPV SUSYs:
 - $\lambda''_{323}: \tilde{g} \rightarrow tbs$
 - $\lambda'_{x33}: \tilde{t} \rightarrow b\ell$
 - $\lambda'_{x31}: \tilde{t} \rightarrow d\ell$
 - $\eta''_{311}: \tilde{t} \rightarrow dd$

Covers different final-state topologies,
for LLP masses from ~10GeV to
~3TeV!

Example high-mass LLP signature: Split SUSY



[Arkani-Hamed, Dimopoulos, 2004]

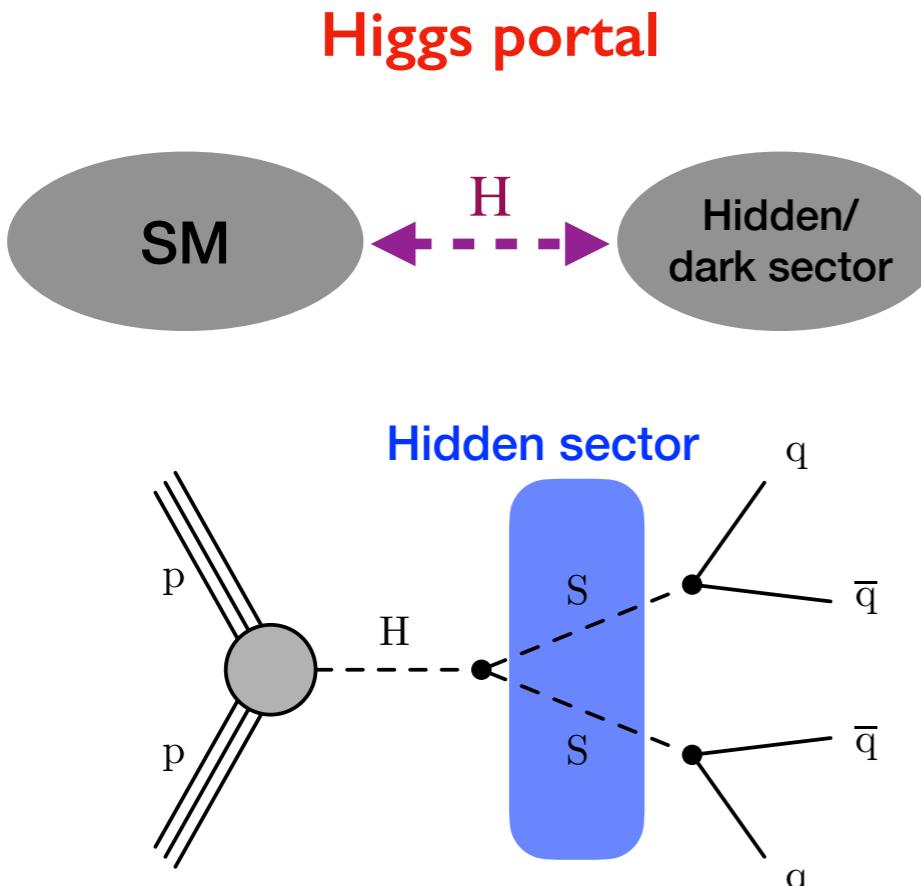


- Signal efficiencies up to ~70% while the search is nearly background free.
- Gluino masses up to 2.6TeV can be excluded.

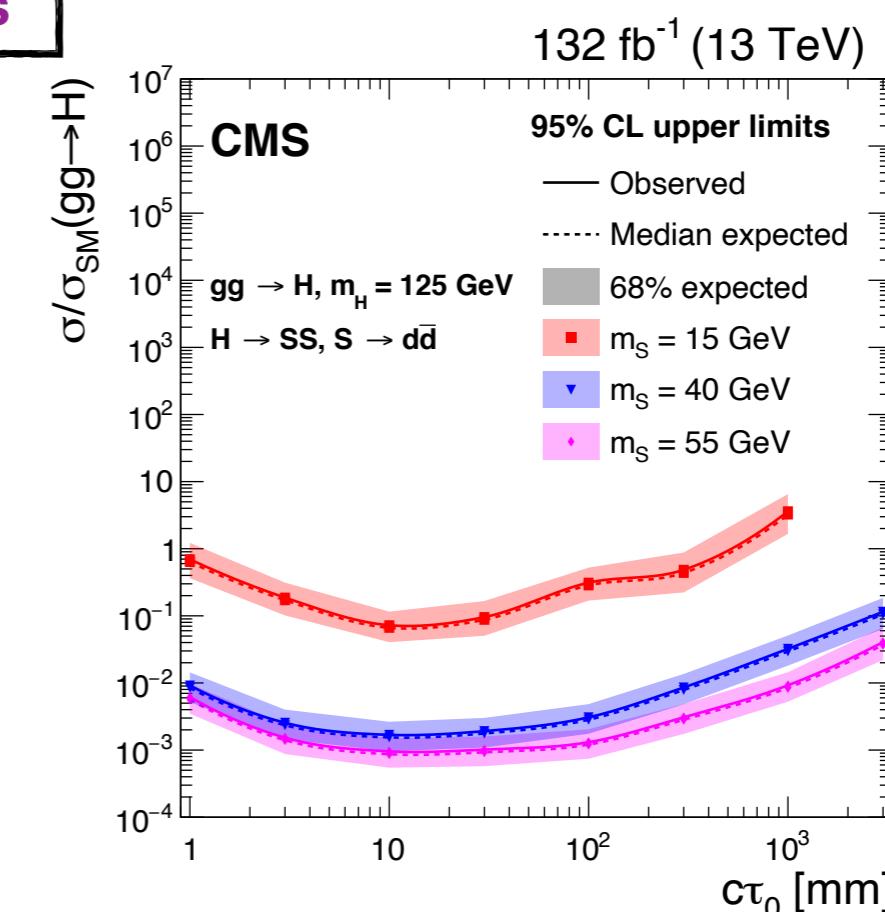
Displaced jets search

- ❖ Expected 0.75 event in the final signal region, observed 1 event
 - Set currently the best limits on a large number of LLP models

Example low-mass LLP signature: exotic Higgs decays



Neutral naturalness, relaxions, ...



- The first LHC search that fills the gap for $c\tau_0 < \sim 1 \text{ m}$;
- Orders-of-magnitude better limits compared to other existing results;
- Currently pursuing an early Run-3 analysis, further orders-of-magnitude improvements expected – stay tuned!

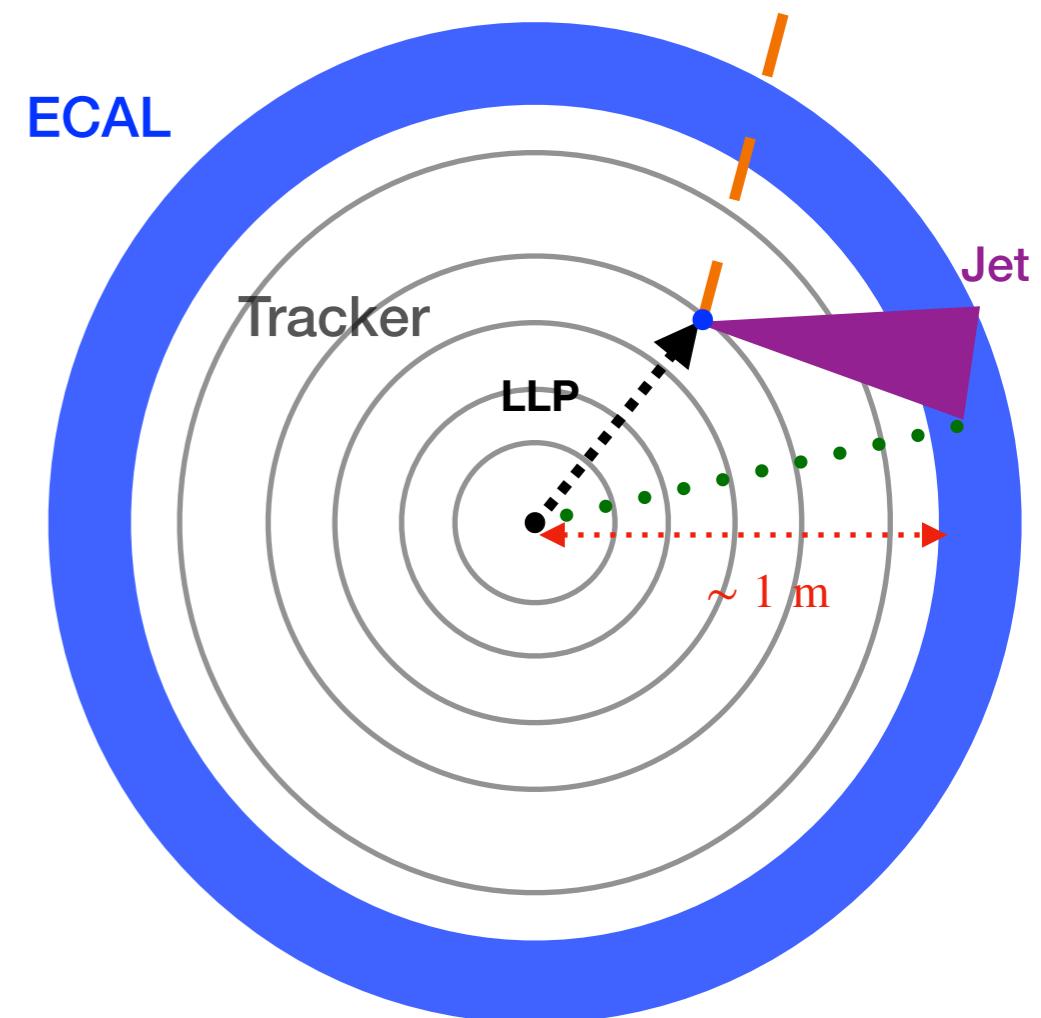
Delayed trackless jets search

❖ Search for hadronic decays of LLPs using delayed and trackless jets

[arXiv: 2212.06695]

- Complementary to the tracker-based displaced-jets search for **higher mass** and **longer lifetime**;

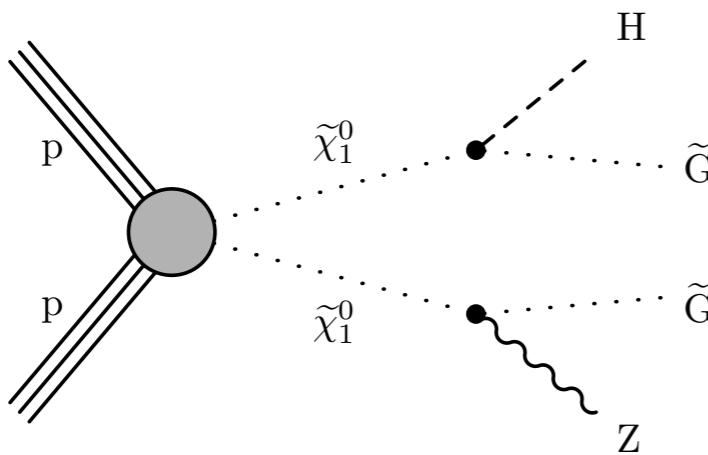
- ECAL timing is used to tag the **delayed time** produced by LLP decays:
 - Delayed time produced by the **path difference** induced by the decay process;
 - Delayed time produced by **slowly-moving heavy LLPs**.
- Additional discrimination power** brought by requiring the **lack of charged (tracking) activities**
 - Tracking efficiencies decrease with larger displacements



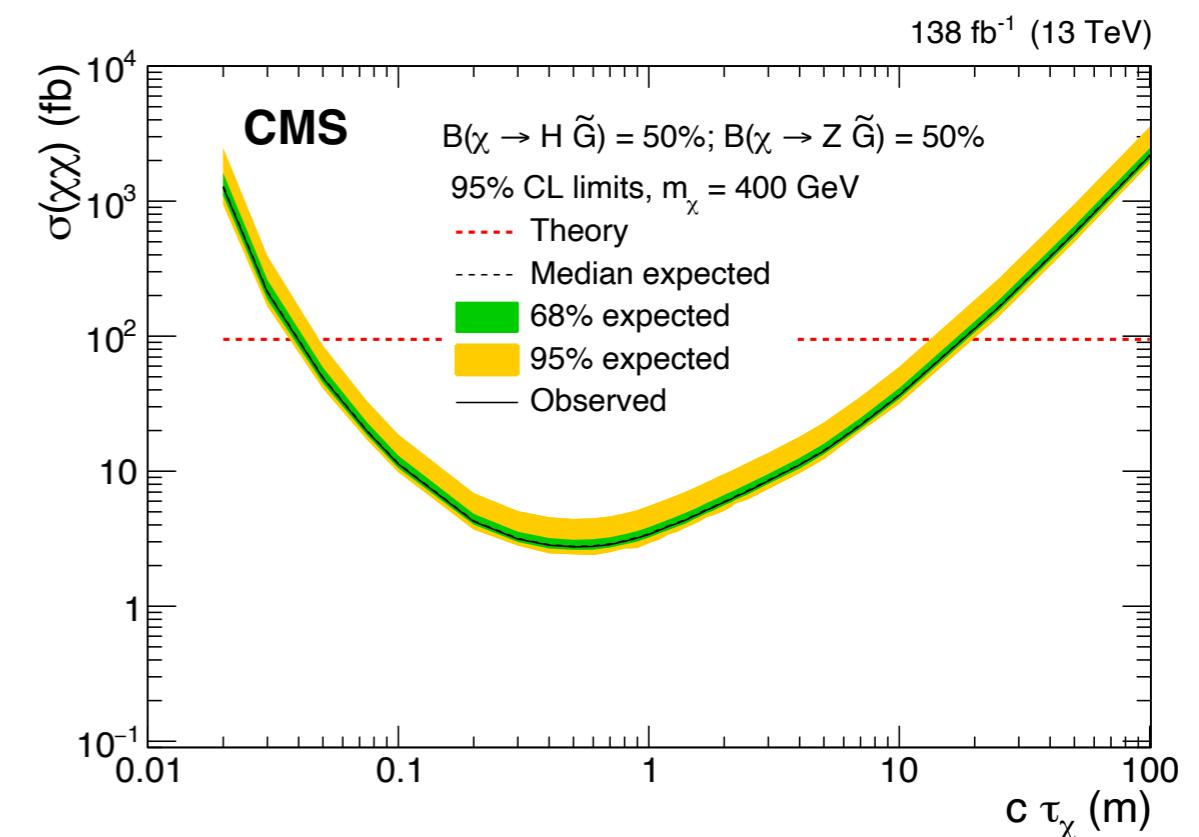
Delayed trackless jets search

❖ Search for hadronic decays of LLPs using delayed and trackless jets

- Benchmark model: gauge mediation with $\tilde{\chi}_1^0$ as the NLSP
 - Gravitino coupling is suppressed by the SUSY-breaking scale → the NLSP is usually long lived in gauge-mediated SUSY.



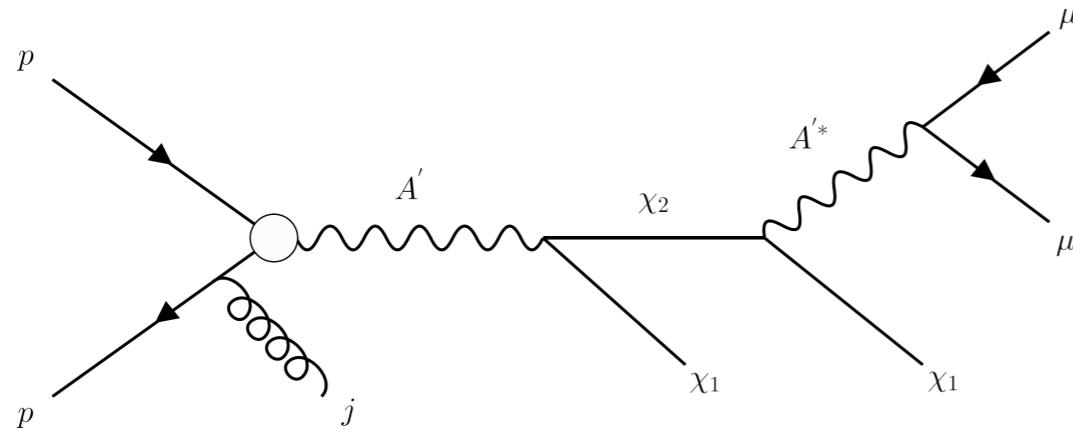
- \tilde{G} is the LSP and stable → triggered using p_T^{miss} ;
- DNN-based jet tagger constructed using delayed time, number of tracks, charged energy fraction, and track-to-PV association information



Inelastic dark matter search

- ❖ Search for inelastic dark matter using displaced muons and missing transverse momentum

[CMS-PAS-EXO-20-010]



A' : dark photon;

χ_1 : dark matter candidate;

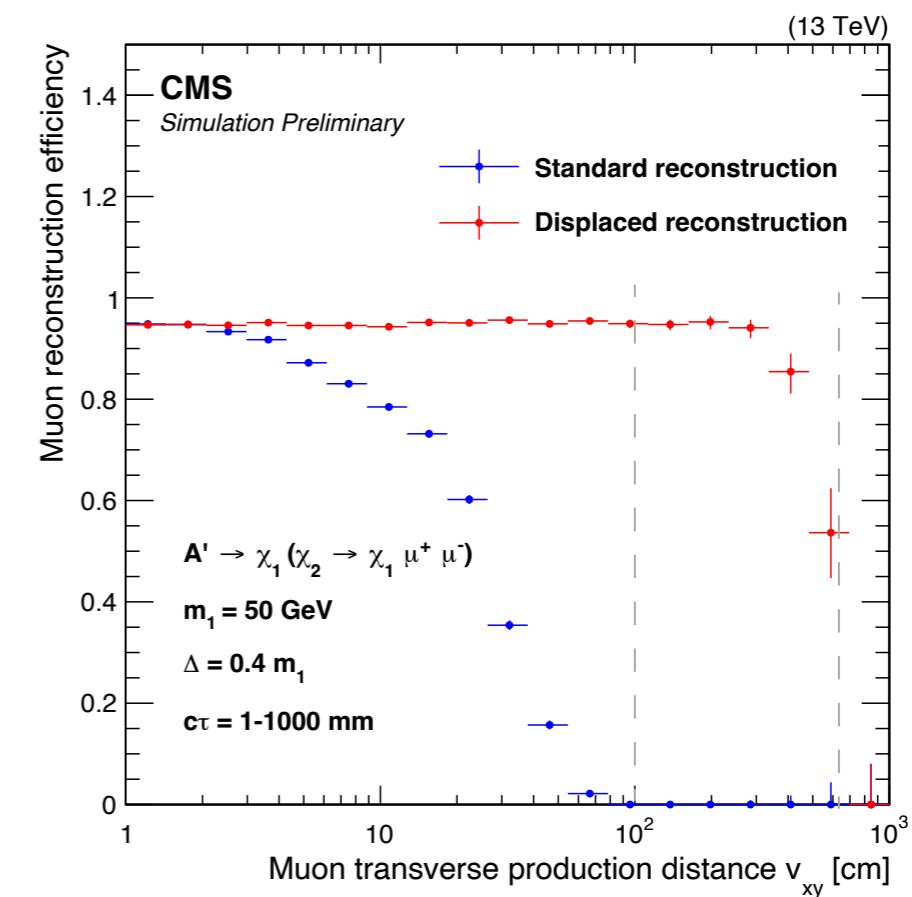
χ_2 : nearly-degenerate excited state,

$$m_{\chi_2} - m_{\chi_1} \ll m_{\chi_1}$$

- Final-state χ_1 s produce p_T^{miss} ;
- The decay of χ_2 is suppressed by the small mass splitting between χ_2 and χ_1
- χ_2 is long lived, producing displaced muons.

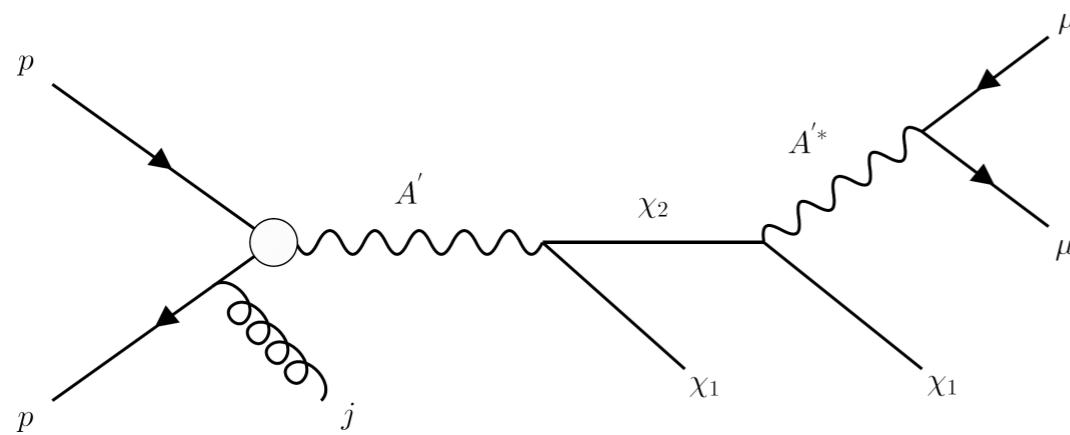
Inelastic dark matter (iDM)

- Dark matter couples to SM only through interacting with a **nearly degenerate excited state**, evading stringent constraints on DM-nucleon/electron scattering from direct-detection experiments.



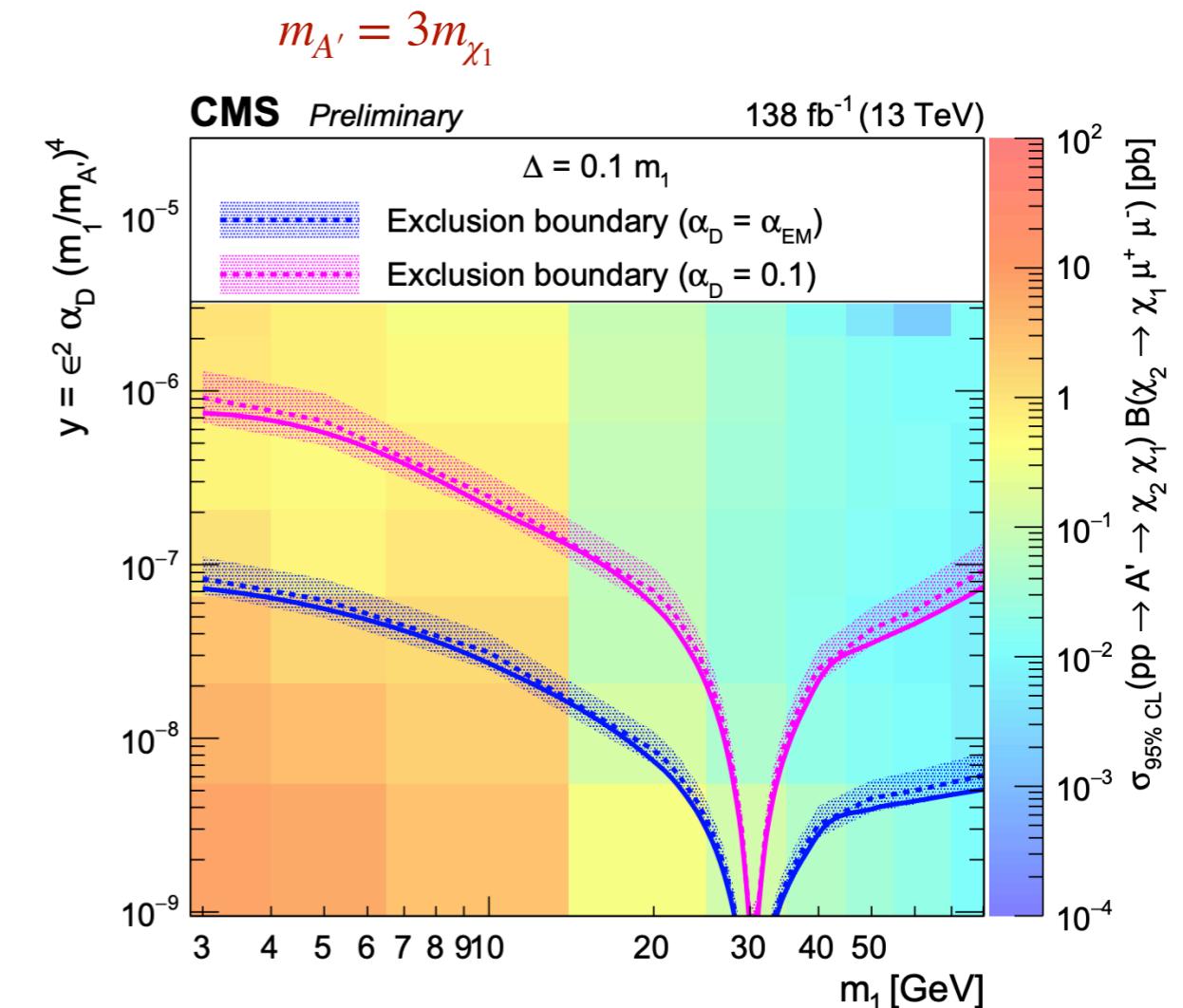
Inelastic dark matter search

- ❖ Search for inelastic dark matter using displaced muons and missing transverse momentum



Main selection variables

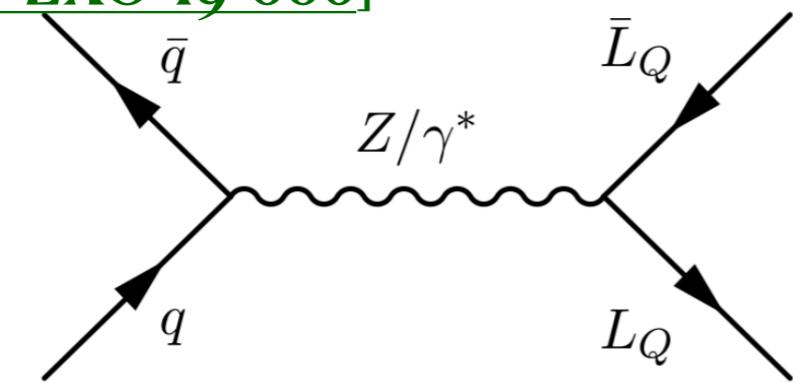
- Muon displacement d_{xy} ;
- Muon isolation;
- $\Delta\phi(p_T^{\mu\mu}, p_T^{\text{miss}})$



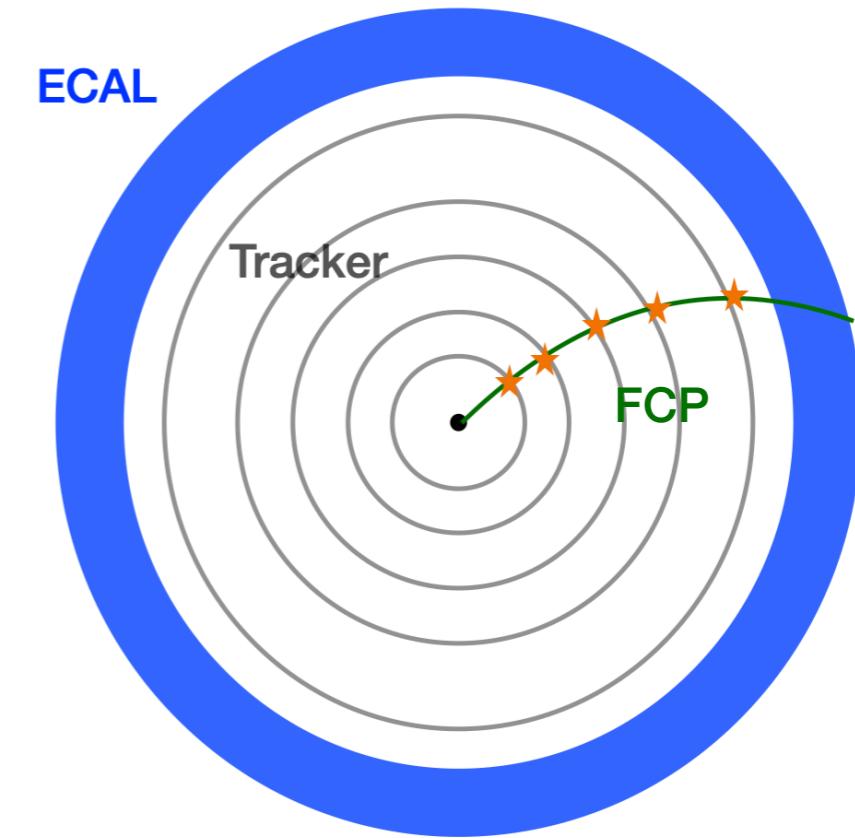
Fractional charged particle search

- ❖ Search for fractional charged particles (FCPs) using anomalously small ionization

[CMS-PAS-EXO-19-006]



Benchmark: DY production of FCPs



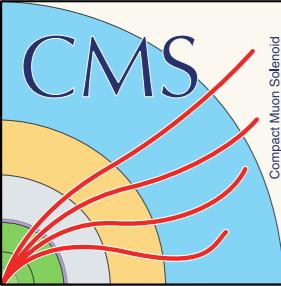
Bethe-Bloch equation

$$-\left\langle \frac{dE}{dx} \right\rangle = K Q^2 \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2m_e c^2 \beta^2 \gamma^2 T_{\max}}{I^2} - \beta^2 - \frac{\delta}{2} \right]$$

FCPs characterized by hits with small dE/dx

FCP tracks identified as the tracks with a large **number of low- dE/dx hits** $N_{\text{hits}}^{\text{low } dE/dx}$

dE/dx thresholds tuned for each layer to ensure a uniform “mistagging” probability for background tracks



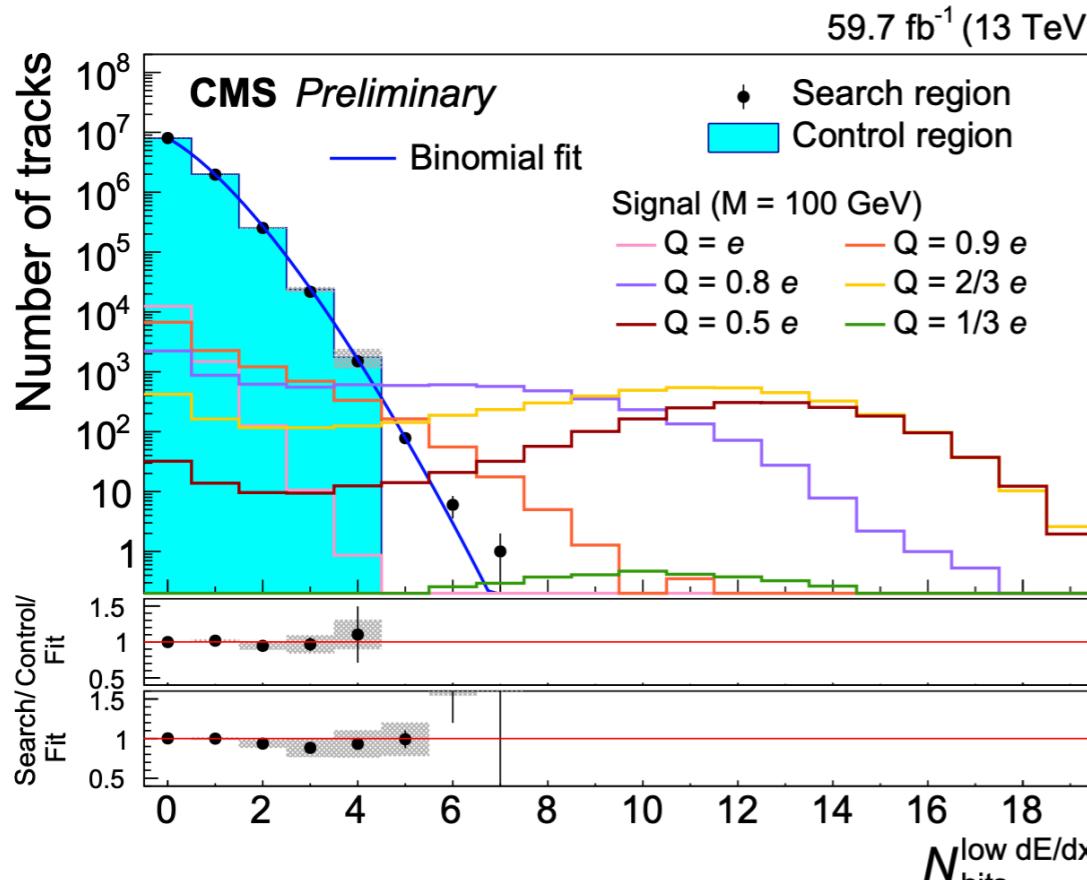
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Fractional charged particle search

- ❖ Search for fractional charged particles (FCPs) using anomalously small ionization

$N_{\text{hits}}^{\text{low } dE/dx}$ as the main search variable



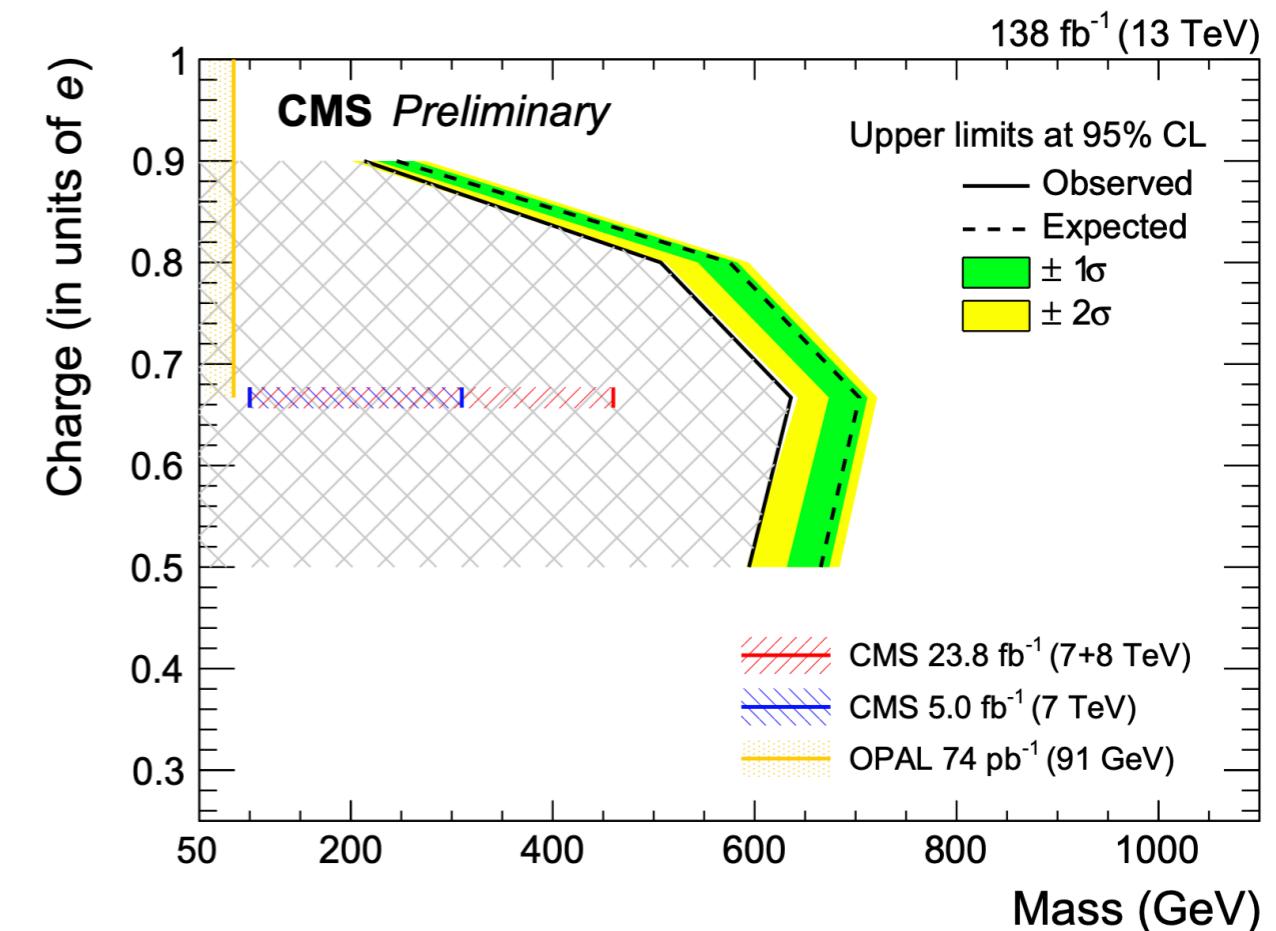
Control region: $80 < m < 100 \text{ GeV}$

Fit performed using low $N_{\text{hits}}^{\text{low } dE/dx}$ bins in the control region to estimate the background yields in the search region

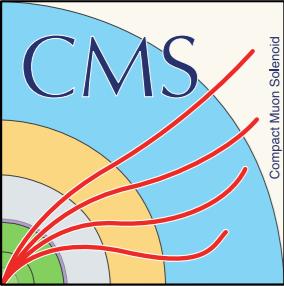
05/09/23

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Limits placed in the mass-charge plane



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Summary and outlook

- ❖ CMS searches cover a large variety of non-conventional signatures, providing world-leading sensitivities in many cases;
- ❖ We are also actively pursuing developments of new techniques in Run 3:

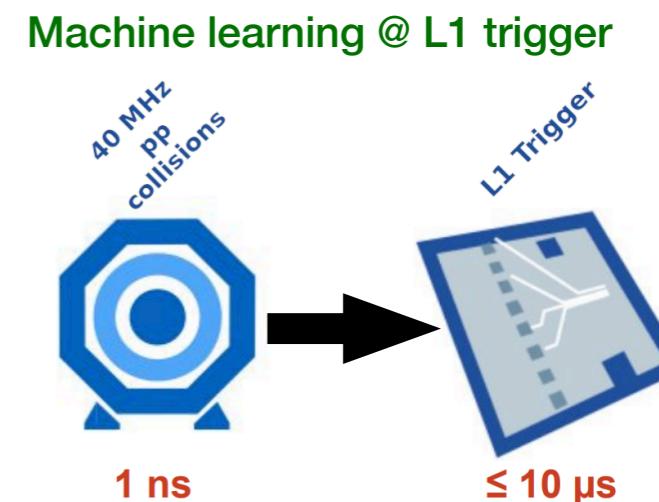
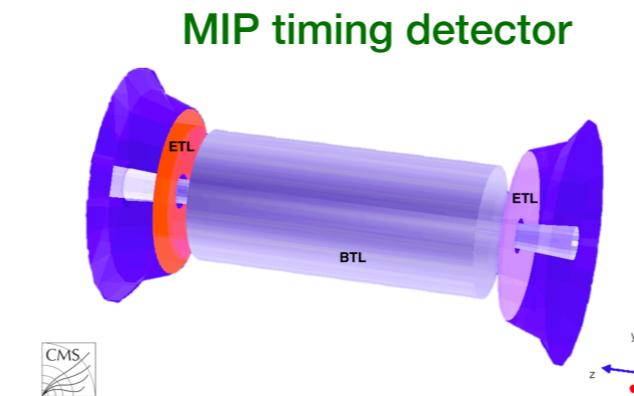
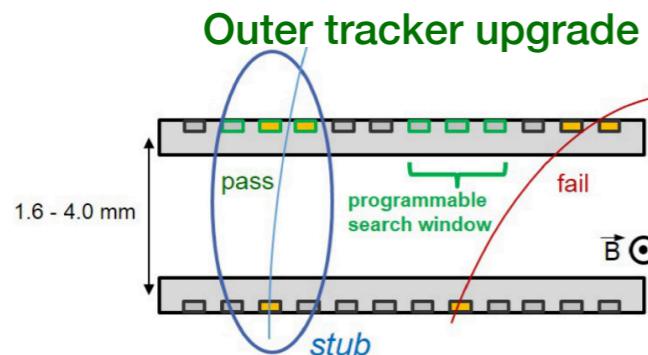
Trigger

Reconstruction

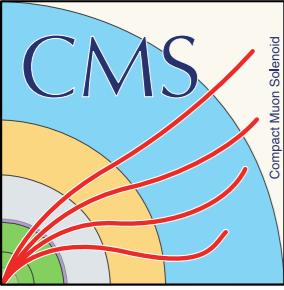
Machine learning

Further orders-of-magnitude improvements can be expected in Run 3

- ❖ New detector technologies with HL-LHC upgrade will also bring many great opportunities



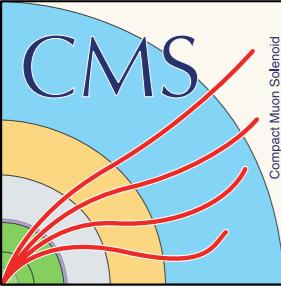
Exciting times ahead!



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Extra slides

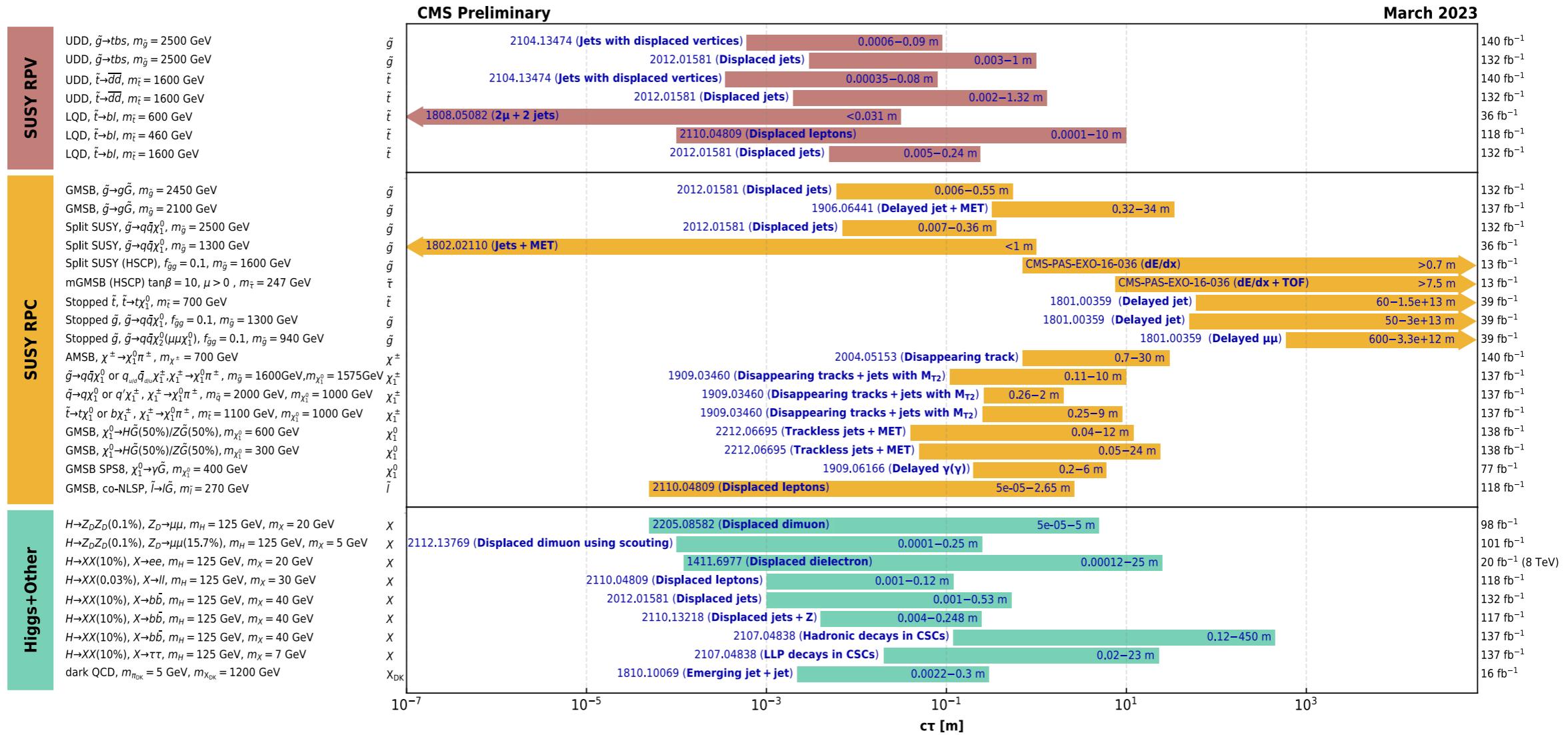


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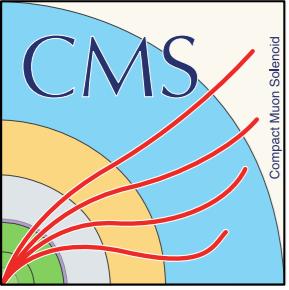


Summary of CMS LLP program

Overview of CMS long-lived particle searches



Selection of observed exclusion limits at 95% C.L. (theory uncertainties are not included). The y-axis tick labels indicate the studied long-lived particle.



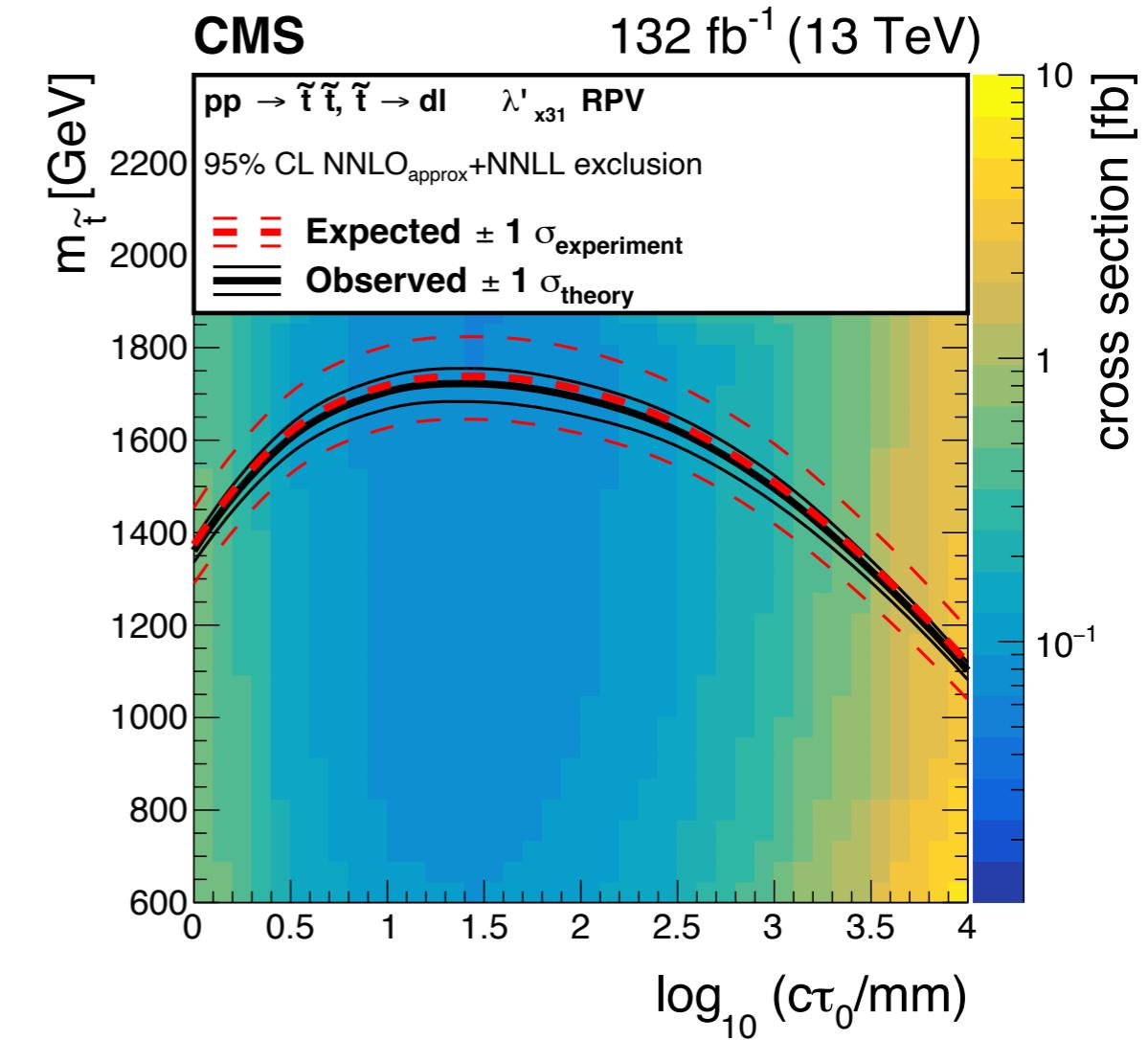
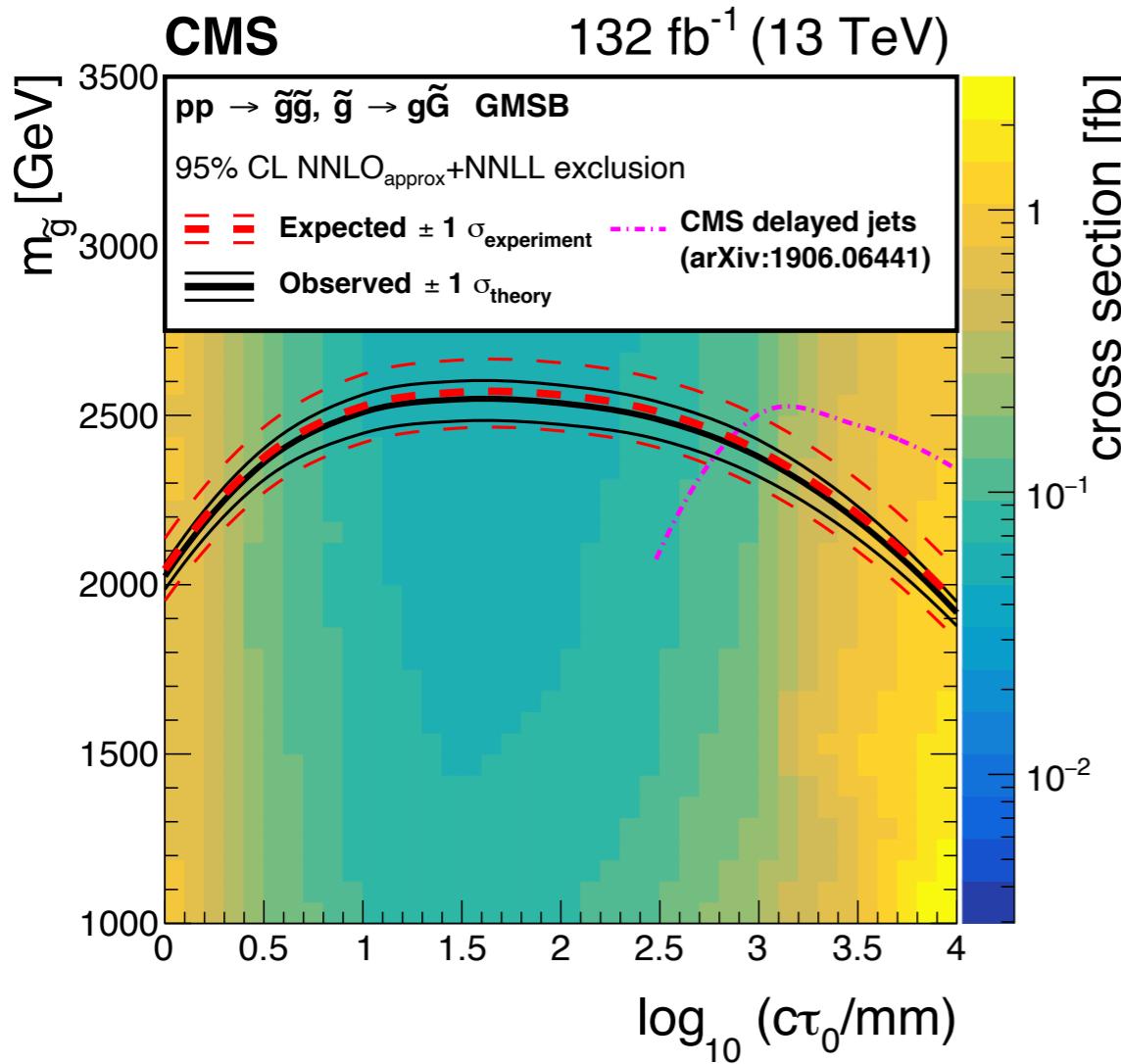
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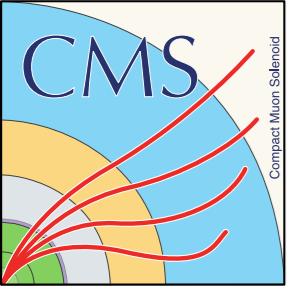


Displaced jets search

$$g \tilde{g} \rightarrow g \tilde{G}$$

$$\tilde{t} \rightarrow d\ell$$





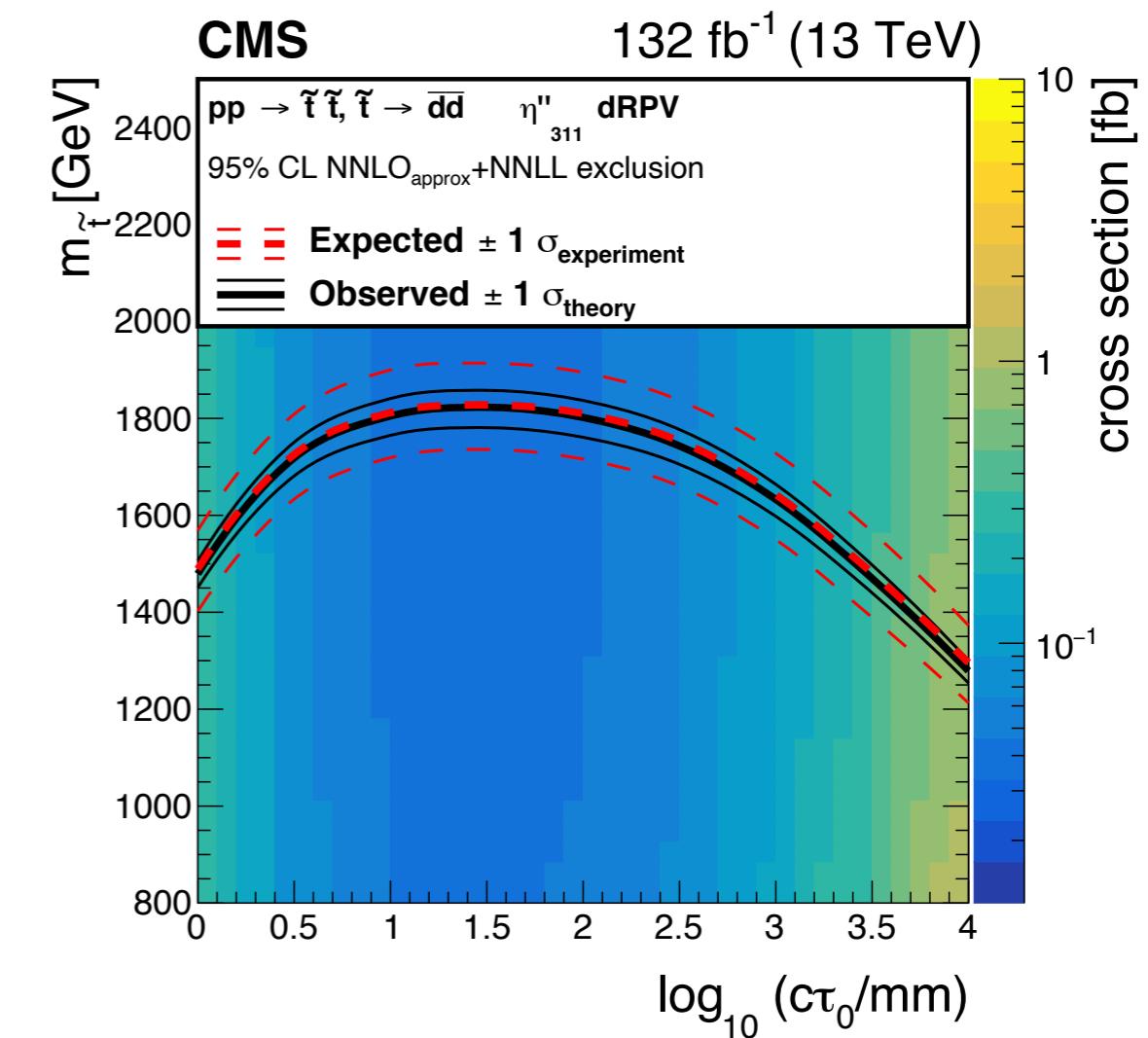
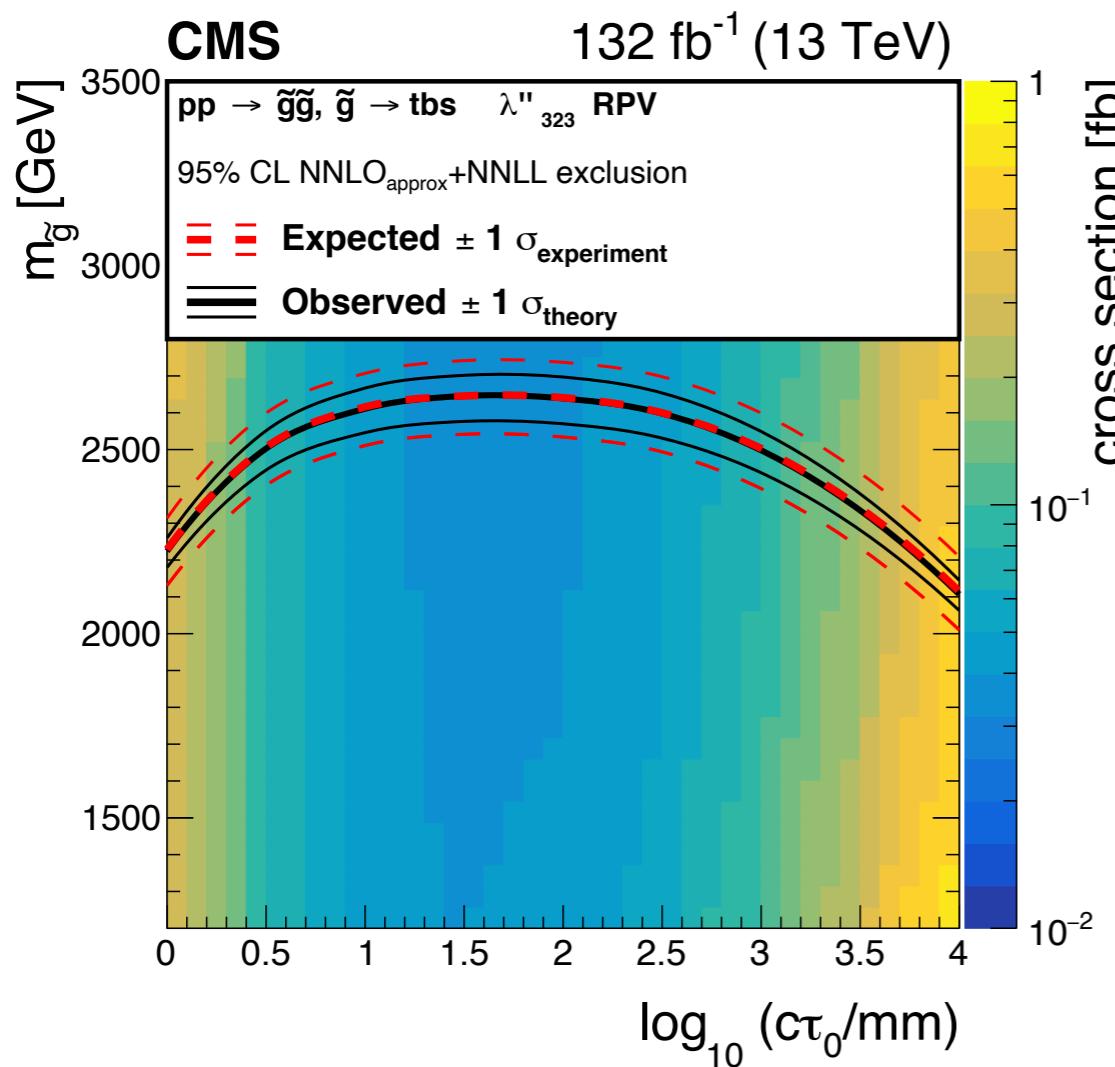
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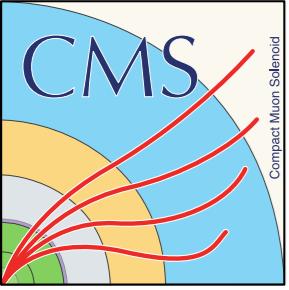


Displaced jets search

$\tilde{g} \rightarrow tbs$

$\tilde{t} \rightarrow \bar{d}\bar{d}$



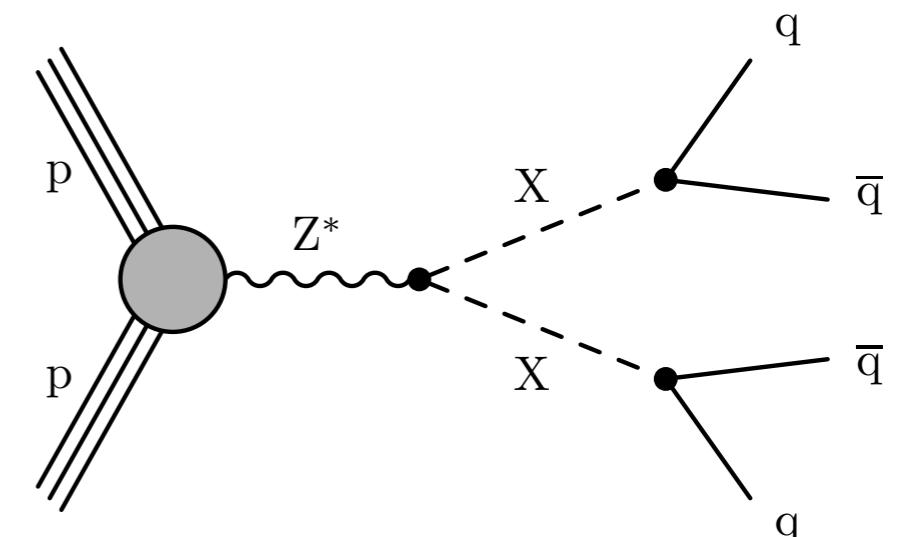
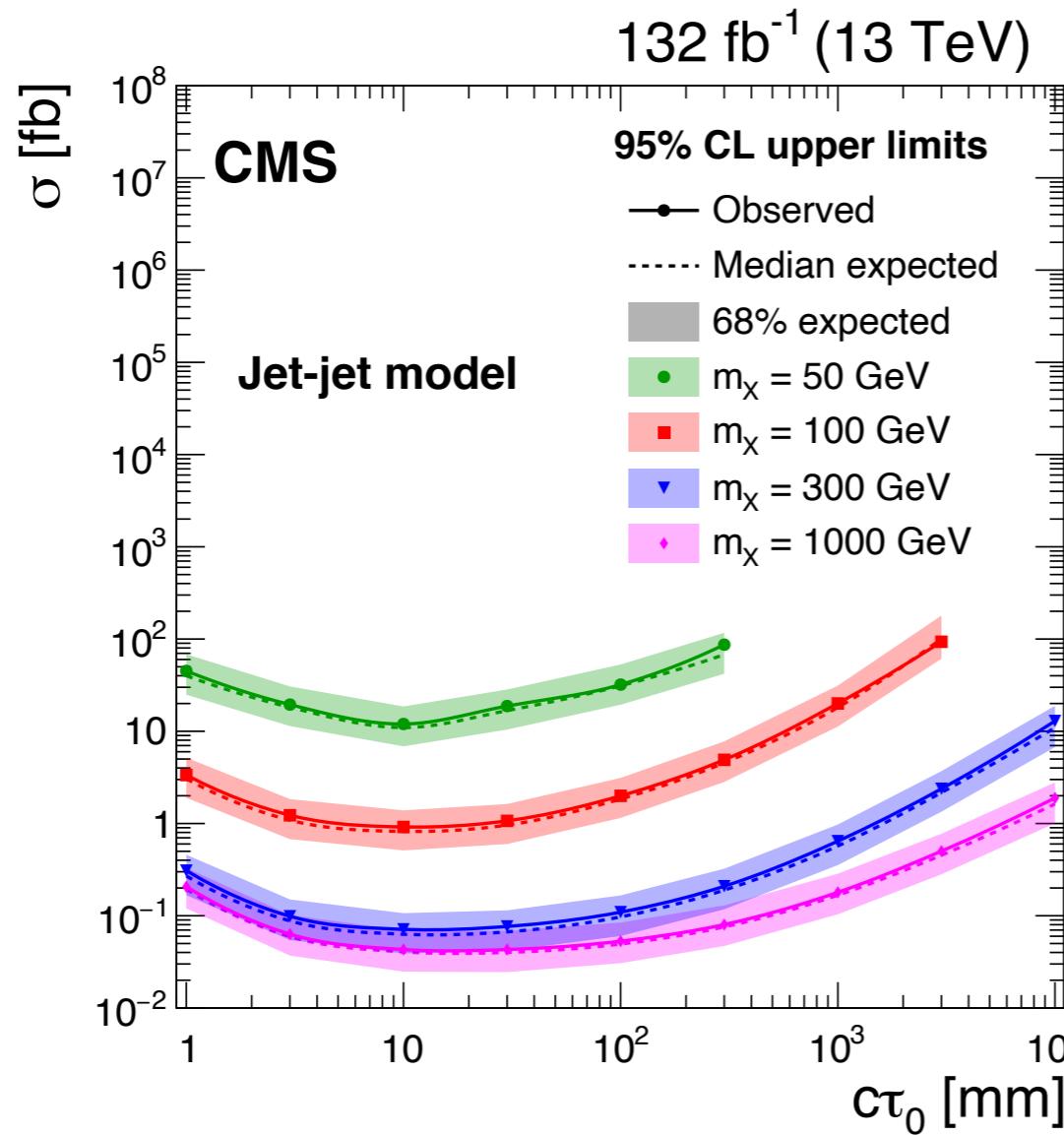


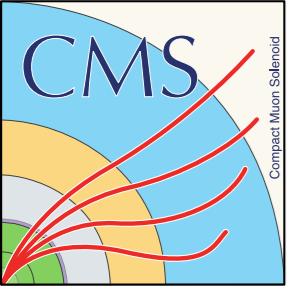
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Displaced jets search

$pp \rightarrow XX \rightarrow 4j$



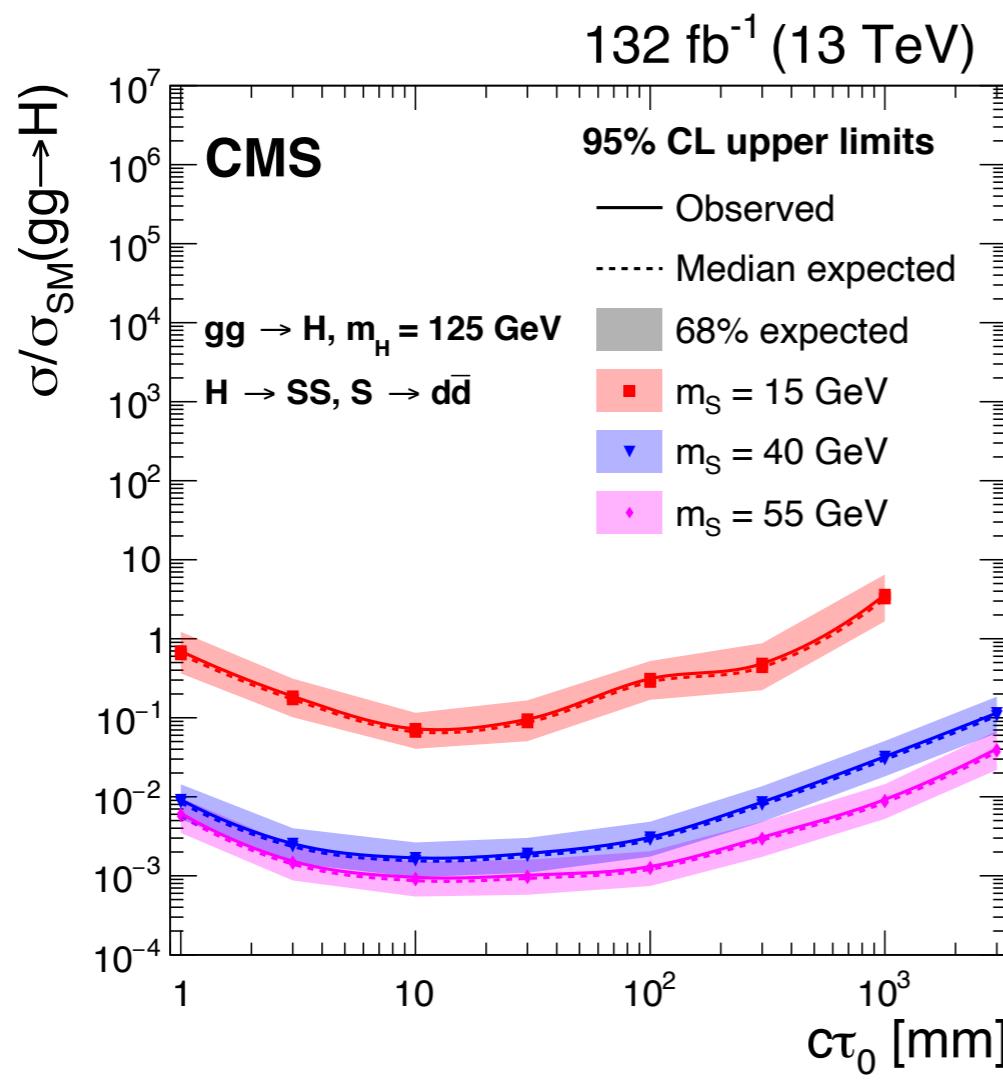


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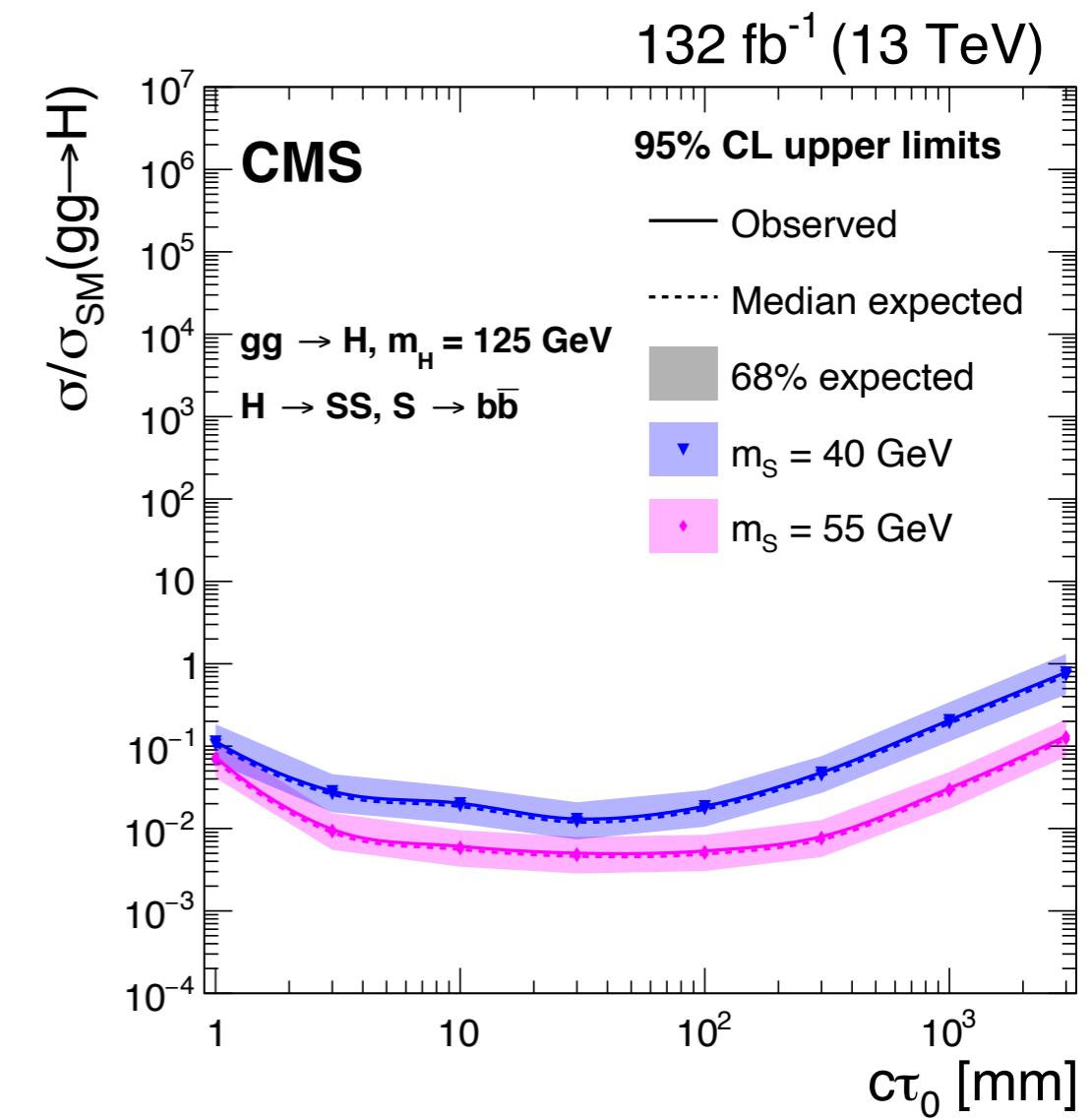


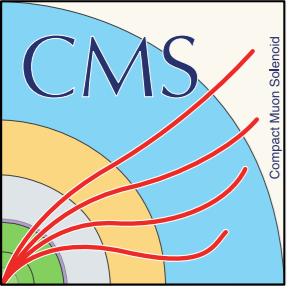
Displaced jets search

125GeV $H \rightarrow SS \quad S \rightarrow dd$



125GeV $H \rightarrow SS \quad S \rightarrow bb$



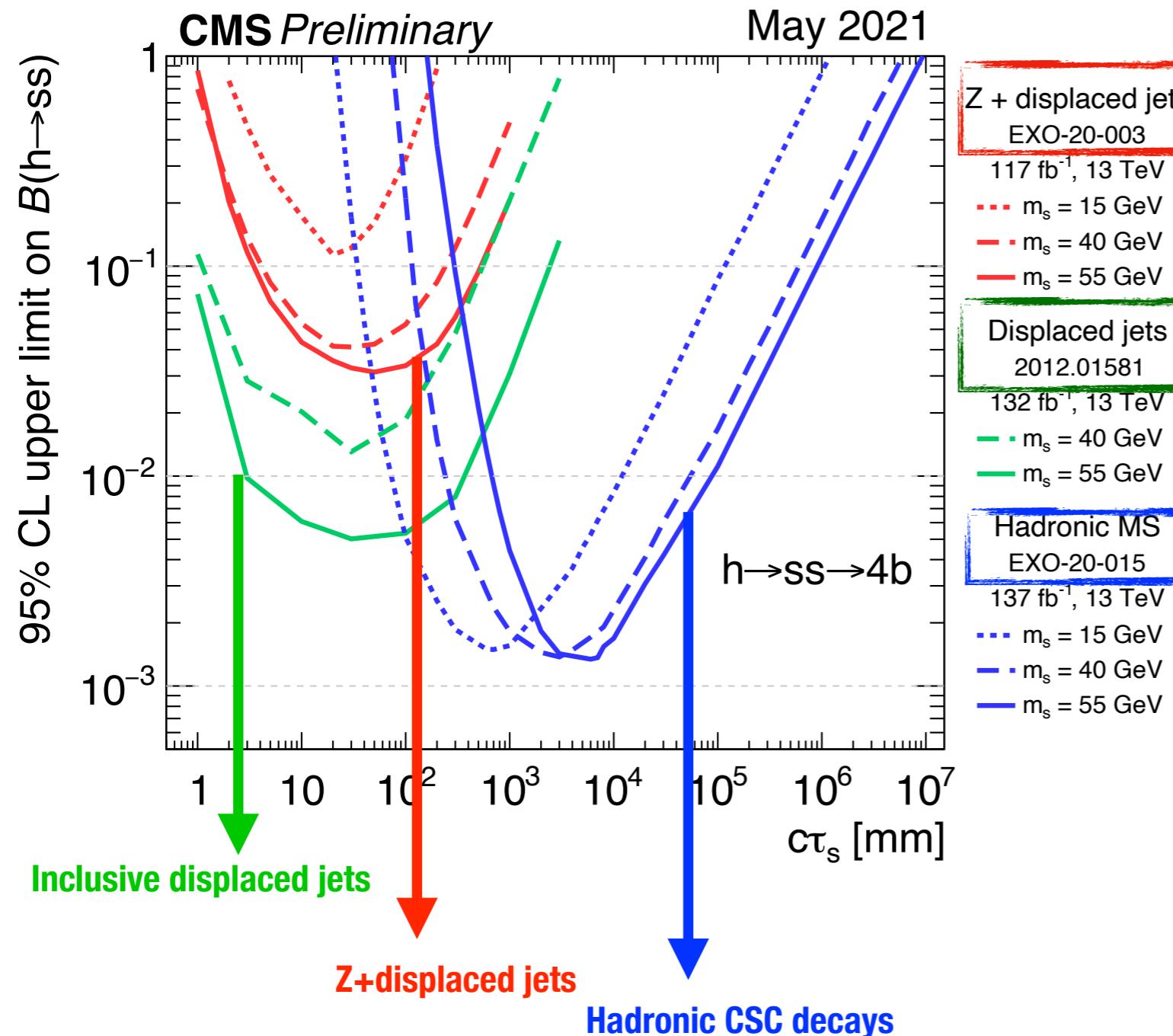


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CMS sensitivities to $H \rightarrow \text{LLPs with hadronic decays}$

125 GeV $H \rightarrow \text{SS} \rightarrow \text{bbbb}$

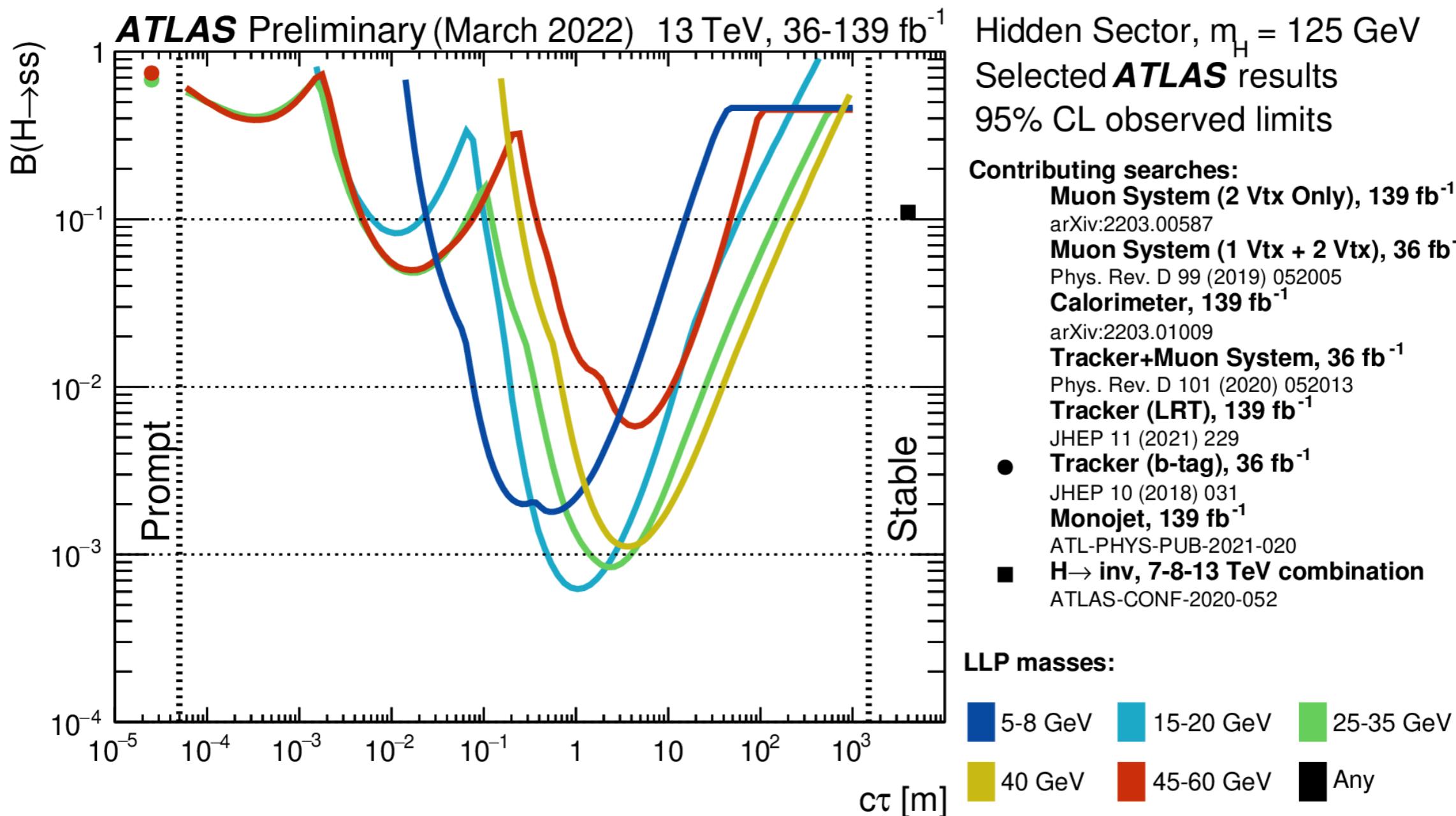


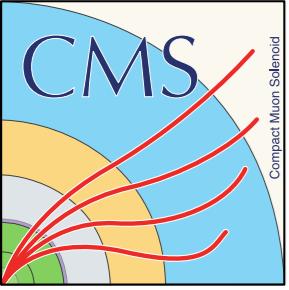
[arXiv: 2110.13218]

[arXiv: 2012.01581]

[arXiv: 2107.04838]

ATLAS sensitivities to $H \rightarrow \text{LLPs}$ with hadronic decays





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CMS sensitivities to split SUSY

